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RADIONUCLIDE UPTAKE BY BEAVER AND RUFFED GROUSE IN THE SERPENT RIVER BASIN

by

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ABSTRACT

Radionuclide levels were measured in tissues, gut contents, and diet items of adult beaver and ruffed grouse from the Serpent River drainage basin (which contains the city of Elliot Lake) and control sites in Ontario, and in beaver and muskrat fetuses from females taken in the same basin.

Levels of radium 226 in beaver bone, muscle and kidney were highest in animals from locations close to uranium tailings; liver levels did not vary by site. Grouse taken near Elliot Lake has higher bone levels of radium 226 than distant controls; levels in other tissues did not vary by site. Environmental radium 226 levels were within ranges previously reported at these or similar locations elsewhere; levels in beaver and grouse gut contents reflected levels in diet items. Fetal beaver tissues had higher radium 226 levels than maternal tissues; fetal liver tissue carried higher levels than other body tissues in general; fetal levels varied with maternal levels but also inversely with fetal size (and thus age). Although muskrat fetal liver had more radium 226 than other tissues, levels were lower than maternal bone levels.

In two grouse and two beaver, selected for their higher tissue levels of radium 226, neither thorium 232 nor thorium 230 were detected in bone, muscle, or liver samples, however other radionuclides were measured: uranium 238 in beaver and grouse bone, muscle and liver; thorium 228 in beaver bone and grouse muscle; polonium 210 was found in bone, muscle, and liver of both beaver and grouse sampled (except in one grouse muscle sample); lead 210 was measurable only in beaver bone and in one grouse liver sample.

Concentration ratios exceeded unity only between some vegetation items and beaver bone at the Elliot Lake site; between vegetation and other beaver tissues values were never more than 0.19. In grouse, the concentration ratios from trembling aspen leaves to bone was 1.04; from other diet items and to other tissues the values were less than unity.

Estimated yearly intakes of radionuclides by people eating beaver and grouse were calculated to be below current allowable levels set by Canadian regulatory authorities.

RÉSUMÉ

Le présent rapport fait état des mesures de radionucléides dans les tissus organiques, le contenu des intestins et les aliments des castors et des gélinottes huppées adultes du bassin hydrographique de la rivière Serpent (qui comprend la ville d'Elliot Lake) et de certains sites de contrôle en Ontario, ainsi que dans les foetus de castors et de rats musqués femelles qui ont été prises dans le même bassin.

La concentration de radium 226 dans les os, les muscles et les reins des castors était le plus élevée chez les animaux pris à proximité de résidus miniers d'uranium; les niveaux dans le foie ne variaient pas d'un site à l'autre. La concentration de radium 226 dans les os des gélinottes près d'Elliot Lake était plus élevée que dans les sites de contrôle plus éloignés; les niveaux dans les autres tissus ne variaient pas d'un site à l'autre. La concentration de radium 226 dans l'environnement demeurait dans la même échelle de données qui avait été rapportée précédemment aux mêmes endroits ou dans des endroits semblables; les niveaux relevés dans le contenu des intestins des castors et des gélinottes correspondaient aux niveaux dans les aliments. La concentration de radium 226 dans les tissus organiques des foetus de castor était plus élevée que dans ceux de la mère; les tissus du foie des foetus contenaient des niveaux plus élevés que tout autre tissu du corps; le niveau chez le foetus variait selon le niveau de la mère, mais variait aussi inversement selon la taille du foetus (et par conséquent selon l'âge). Même si le foie des foetus de rat musqué contenait plus de radium que les autres tissus, les niveaux étaient inférieurs aux niveaux dans les os de la mère.

Dans deux gélinottes et dans deux castors, choisis à cause de leur plus forte concentration de radium 226 dans les tissus, on n'a décelé aucune trace de thorium 232 ou de thorium 230 dans les échantillons d'os, de muscles ou de foie, mais on a pu mesuré la présence des radionucléides suivants : de l'uranium 238 dans les os, les muscles et le foie des castors et des gélinottes; du thorium 228 dans les os des castors et les muscles des gélinottes; du polonium 210 dans les échantillons d'os, de muscles et de foie des castors et des gélinottes (sauf dans un échantillon de muscle de gélinotte); du plomb 210, mais seulement dans les os des castors et dans un échantillon de foie des gélinottes.

Les ratios de concentration ont dépassé 1 seulement dans le cas de certains végétaux et des os de castors à Elliot Lake; les valeurs entre les végétaux et les autres tissus des castors n'ont jamais dépassé 0,19. Pour les gélinottes, le ratio de concentration des feuilles de tremble et des os était de 1,04, tandis que le ratio des autres aliments et des autres tissus était inférieur à 1.

Selon les calculs, on a estimé que les incorporations annuelles de radionucléides des personnes qui mangent du castor et de la gélinotte huppée étaient inférieures aux niveaux admissibles actuels établies par les autorités réglementaires canadiennes.

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EXECUTIVE SUMMARY

Radionuclide levels measured in: bone, muscle, kidney, and liver tissues, and gut contents, of 194 beaver and 47 ruffed grouse; liver and pooled body tissues of 17 beaver and 14 muskrat fetuses; vegetation; and water samples from the Serpent River drainage basin (which contains the city of Elliot Lake) and the vicinity of Sudbury, Ontario (130 km distant), showed variation by site, tissue, and species.

Beaver from contaminated sites near U tailings at Elliot Lake had the highest mean concentration of ^{226}Ra in their bones (112.7 mBq.g^{-1} dry weight); beaver from less contaminated sites in Elliot Lake, from the Serpent River, and from a local control area were similar, those from the Serpent River did not differ from those taken near Sudbury. Mean levels of ^{226}Ra in muscle of beaver taken at Elliot Lake (2.9 mBq.g^{-1}) and in the Serpent River (2.2 mBq.g^{-1}) were similar, but both were higher than in distant controls (0.9 mBq.g^{-1}); levels in muscle of beaver taken near the mouth of the river were similar to distant controls. Beaver liver values showed no variation with site. Kidney levels were higher in Elliot Lake (9.2 mBq.g^{-1}) than down-stream samples (4.0, 4.3 mBq.g^{-1}), and all these values were higher than distant controls (2.0 mBq.g^{-1}). Levels of ^{226}Ra in stomach chyme of beaver from Elliot Lake (61.9 mBq.g^{-1}) were similar to values in vegetation consumed by the animals, and higher than levels in animals taken down-stream (12.5, 9.3 mBq.g^{-1}). Fetal tissues of beaver had higher ^{226}Ra levels than all maternal tissues: fetal liver tissue carried higher levels than other body tissues in general; fetal levels varied with maternal levels but also inversely with fetal size (and thus age). Although muskrat fetal liver had more ^{226}Ra than other tissues, levels were lower than maternal bone levels.

Grouse bone ^{226}Ra levels in Serpent River basin populations (circa 20 mBq.g^{-1}) did not differ from local controls (31.7 mBq.g^{-1}), but were higher than distant controls (8.0 mBq.g^{-1}); muscle, liver, and kidney ^{226}Ra concentrations did not differ significantly among populations. Levels of ^{226}Ra in the crop contents, chyme, and chyle of birds taken from the Elliot Lake area did not differ significantly and were similar to those found in food items consumed by the birds.

Environmental levels fell within ranges previously reported at the sites, or at similar locations elsewhere: In woody plants, highest levels of ^{226}Ra were in white birch near the tailings (252.2 mBq.g^{-1} in leaves) and from 32.0 to 135.7 mBq.g^{-1} in leaves and twigs of other trees in the vicinity. Fungi levels of ^{226}Ra ranged to 215.4 mBq.g^{-1}, with some variation by site. River and lake waters had levels ranging from 118.1 mBq.l^{-1} of dissolved ^{226}Ra near the U tailings to 12.1 mBq.l^{-1} at the distant control site.

Levels of ^{232}Th, ^{230}Th were < 0.1 μg.g^{-1} and < 5.0 mBq.g^{-1} respectively (detection

limits) in bone, muscle, and liver tissue in the two grouse and two beaver with the highest levels of ^{226}**Ra**. Other radionuclides were measurable in some tissues: **U**-238 in bone at 0.3 $\mu g.g^{-1}$ in beaver, and 0.4 $\mu g.g^{-1}$ in grouse, in muscle to 0.3 $\mu g.g^{-1}$ in beaver and 0.2 $\mu g.g^{-1}$ in grouse, in liver to 0.4 $\mu g.g^{-1}$ in beaver and 1.0 $\mu g.g^{-1}$ in grouse; **Th**-228 was found only in beaver bone (10 and 15 $mBq.g^{-1}$), and grouse muscle (8.0 $mBq.g^{-1}$); **Po**-210 was found in bone, muscle, and liver of both beavers sampled (maxima: 160.0, 75.0, 65.0 $mBq.g^{-1}$ respectively) and in corresponding tissues of both grouse (maxima: 24.0, 7.0, 16.0 $mBq.g^{-1}$) with the exception of one muscle sample; **Pb**-210 occurred in beaver bone (to 190 $mBq.g^{-1}$) but was undetectable in other beaver tissues (< 50 $mBq.g^{-1}$); among grouse tissues, only one liver sample had measurable levels (50.0 $mBq.g^{-1}$).

Concentration ratios (CRs) (tissue levels, fresh weight basis, divided by vegetation values, similarly expressed) of beaver from the Elliot Lake site exceeded unity only between some vegetation items and bone (maximum 5.38 between aspen leaves and bone); between vegetation and other tissues values were never more than 0.19. CRs from a vegetation mix ('diet') reflecting published information on beaver dietary habits were 1.31 from 'diet' to bone, and less than 0.04 between 'diet' and other tissues. The CR from beaver chyme to bone was 5.25, and less than unity in the other three cases. Water to tissue CRs, based on dissolved ^{226}**Ra** levels ($mBq.l^{-3}$) ranged to 572.05. In grouse, the CR from trembling aspen leaves to bone was 1.04; from other diet items and to other tissues the values were less than unity. CRs from a vegetation mix reflecting published information on grouse dietary preferences to grouse tissues were less than unity in all cases. From gut contents, the CR to tissues ranged from 1.42 to 2.31 to bone (depending on region of gut sampled) but was less than unity to other tissues. Water to tissue CRs, based on dissolved ^{226}**Ra** levels ($mBq.l^{-3}$) ranged to 110.06.

Intakes of radionuclides measured in beaver and grouse tissues were estimated from a diet including 175 g of muscle, 17.5 g of liver, and 1.8 g of bone each day. These estimated yearly intakes were less than limits currently established in Canada.

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TABLE OF CONTENTS

page

ABSTRACT ii
EXECUTIVE SUMMARY iii
ACKNOWLEDGEMENTS v
TABLE OF CONTENTS vi
LIST OF TABLES viii
LIST OF FIGURES ix
INTRODUCTION
purpose 1
outline 1
background
modelling 2
natural history 3
METHODS AND MATERIALS
areas 6
study 6
control 6
animal
numbers 8
collecting 8
processing: measurement, dissection, and tissue separation 9
aging 9
plant
collecting 10
processing 11
water
collecting 11
analytical methods
glassware 12
animal tissue processing 12
plant tissue processing 13
water processing 13
analysis of ^{226}Ra 13
analysis of other radionuclides 13
quality assurance 14

page

data

statistics and transformations....14
presentation and calculations....16
concentration ratios....16
RESULTS and DISCUSSION....18
beaver
bone....22
muscle....23
liver....24
kidney....25
chyme....26
grouse
bone....28
muscle....29
liver....30
kidney....31
gut contents....32
maternal and fetal tissues....33
vegetation
woody plants....34
fungi....36
water....36
other radionuclides....37
concentration ratios....39
estimates of annual intakes....44
quality assurance....47
CONCLUSIONS....48
LITERATURE CITED....50
APPENDIX I. Beaver specimens processed in study.
APPENDIX II. Grouse specimens processed in study.
APPENDIX III. Beaver and muskrat fetuses processed in study.
APPENDIX IV. Water quality at locations in the Serpent River Basin.
APPENDIX V. Normality and data transformations.

LIST OF TABLES

table		page
1	Numbers of beaver and grouse specimens from study and control areas	18
2	Ra-226 in maternal and fetal tissues of beaver and muskrat	33
3	Ra-226 in woody plants from study and control areas.	34
4	Ra-226 in fungi from study and control areas	36
5	Levels of ^{226}Ra in water samples from study and control areas	36
6	Radionuclides in tissues of beaver and grouse from Elliot Lake	38
7	Concentration ratios to tissue compartments of beaver from Elliot Lake.	39
8	Concentration ratios to tissue compartments of grouse from Elliot Lake.	41
9	Levels of ^{226}Ra (mBq.g^{-1} dry weight) in beaver and grouse bone: repeated measures	47

LIST OF FIGURES

figure		page
1	Kill sites of beaver taken in the Serpent River drainage basin	19
2	Kill sites of grouse taken in the Serpent River drainage basin	20
3	Ra-226 in bone of beaver from study and control areas	22
4	Ra-226 in muscle of beaver from study and control areas	23
5	Ra-226 in liver of beaver from study and control areas	24
6	Ra-226 in kidney of beaver from study and control areas.	25
7	Ra-226 in chyme of beaver from study areas.	26
8	Ra-226 in bone of grouse from study and control areas.	28
9	Ra-226 in muscle of grouse from study and control areas.	29
10	Ra-226 in liver of grouse from study and control areas	30
11	Ra-226 in kidney of grouse from study and control areas.	31
12	Ra-226 in gut content of grouse from Elliot Lake area	32

INTRODUCTION

purpose

This study was done to extend our understanding of the movement of radionuclides through a watershed ecosystem containing wastes from U mines and mills, and to assess any radiological hazards faced by human consumers of wild game taken in the watershed.

Radionuclides were studied in components of the Serpent River drainage basin ecosystem which contains tailings deposits of the U extraction operations at Elliot Lake, Ontario. Radionuclide levels, measured in body tissues of animals (including fetuses), in the plants on which the animals feed, and in water collected in the basin, were used to calculate concentration factors used in modelling the movements of ^{226}Ra in the ecosystem and the annual radionuclide intakes of humans consuming wild meat. Samples from control sites were taken to provide background values of animals, vegetation, and water not associated in any way with U wastes.

outline

To achieve the purpose of the study, ^{226}Ra levels were measured in: a) bone, muscle, liver, and kidney tissues of beaver (***Castor canadensis***) and ruffed grouse (***Bonasa umbellus***) taken in the Serpent River basin, and from control sites, b) vegetation items consumed by the animals, and whenever possible, their gut contents, c) water used by the animals for drinking and, by beaver, as their living medium, d) fetal tissues of beaver and muskrat (***Ondatra zibethica***) from contaminated areas.

Other radionuclides (^{238}U, ^{232}Th, ^{230}Th, ^{228}Th, ^{210}Pb, and ^{210}Po) were measured in tissues of two beaver and two grouse with the highest tissue levels of ^{226}Ra observed in the study.

The levels of ^{226}Ra obtained in the study were used to calculate

concentration ratios from plant and water to animal tissues, and to estimate annual radionuclide intake by human consumers of these animals.

background

Modelling movements of radionuclides through ecosystems requires calculation of transfer parameters among biologically connected compartments within the system. These compartments may be in either the abiotic (e.g. water and substrate) or the biotic (e.g. plants, herbivores, and predators) components of the ecosystem. Materials may move from one compartment to another by mechanisms as varied as diffusion and active excretion against concentration gradients. Routes connecting compartments may be as short and simple as water absorption by plant root hairs from spaces in the surrounding substrate, or as long and involved as the movement of food through the complex stomach and intestines of ruminants, or the double pass through the gut of coprophagous animals (e.g. beaver, see below).

The 'concentration ratio' (CR) is a transfer parameter calculated as the ratio between concentrations in connected compartments of a model such as an animal's diet (vegetation) and its tissue (e.g. bone). Information on radionuclide movements in the progression substrate-vegetation-animal (tissue) are known in only a few cases. Food and tissues of small terrestrial mammals (voles, ***Microtus pennsylvanicus***) and larger game animals (deer, ***Odocoileus virginianus***, moose, ***Alces alces***) from the vicinity of the U tailings, or the drainage from these tailings, at Elliot Lake, Ontario, have been studied under wild and natural conditions to provide data useful in this regard (Burns et al. 1987; Cloutier et al. 1983, 1985a,b; and 1986; MacLaren 1978, 1987). Ra-226 levels in fæces of hares (***Lepus americanus***) from the area have been reported (Clulow et al. 1986) as have levels in cutworms (***Agrotis ipsilon***) eaten by gulls (***Larus argentatus***) visiting the tailings (Clulow et al. 1988). MacLaren (1978) gave levels of ^{226}**Ra** in muscle tissue of four beaver from the vicinity of Quirke Lake. Information on radionuclide levels in food or tissues of game birds of the area is limited: levels of ^{226}**Ra** in muscle tissue of three

ducks and two grouse are given by MacLaren (1978).

The work reported here was designed to provide data necessary for calculating ^{226}**Ra** concentration ratios between water and vegetation on one hand, and tissues of aquatic mammals (beaver) and game birds (grouse), on the other. In addition, other radionuclides in the animal tissues were measured. Animals are eaten by trappers and hunters of the area, including members of the Serpent River Indian Band near the mouth of the river, and information on tissue ^{226}**Ra** and other radionuclide levels were sought to assess human exposure to radionuclides by ingestion of wild game. Fetuses were found in four beaver taken in this study, and in two muskrats taken as part of another study. Levels of ^{226}**Ra** in fetal tissues were compared to maternal levels to see if radionuclide concentration occurred during the early stages of development.

Natural history of the study animals, especially their food habits and movements, was considered in the design of the study and subsequent interpretation of results.

Both beaver and grouse consume plant species in proportions which vary with location and season; neither take appreciable amounts of animal material in their diets. In his review, Hill (1982) indicated that many woody plants are utilized by the beaver; the numbers of plant species used range from three in northern populations to 38 in South Carolina. The animals eat vegetation from about four weeks of age and exhibit coprophagy - the habit of eating faecal pellets direct from the anus and passing food through the gut a second time. Beaver prefer such trees as aspens[1] (='poplars', ***Populus spp.***) and willows (***Salix spp.***) when available, but frequently take maples (***Acer spp.***) and alders (***Alnus spp.***). Plants (leaves, buds, twigs, branches, roots, bark, and fruit) are consumed fresh in the growing season. In winter, material is eaten which has been

[1] Plant names follow FC (1961).

stored from the previous summer and fall in floating caches. Belovsky (1984), studying beaver in Michigan (Isle Royale, Lake Superior), calculated an adult beaver (15 kg) requires about 1,213 $kcal.d^{-1}$, and that some 625 g dry weight of vegetation may be consumed per day to meet this requirement. Adult beaver have a calculated maximum digestive capacity of some 3,458 g wet weight of vegetation per day. Belovsky observed beaver cutting woody vegetation up to 48 m from the edge of the water in which they lived. He also reported that some species of maple (***Acer spp.***) and birch (***Betula spp.***) were preferred over others, and that alder, dogwood (***Cornus spp.***), mountain ash (***Sorbus spp.***), fir (***Abies spp.***), or cedar (***Thuja spp.***) were not selected to any degree. He also noted they ate quantities of aquatic macrophytes. Jenkins and Busher (1979) cited work indicating that roots, rhizomes, and runners of water lilies (***Nuphar sp.*** and ***Nymphea sp.***) contribute to winter diet in some parts of the beaver's geographic range. Trappers in the vicinity of Elliot Lake and Sudbury report that beaver in the area favour aspen, birch, and willow, but also take white pine (***Pinus strobus***) quite readily, that animals consume branches up to 1 cm in diameter in their entirety, and that caches of winter food are contained in cribs consisting of branches of species not favoured for eating. Personal observation confirmed these reports. Signs of beaver activity (felling, gnawing, and tooth marks) were sought at each field collecting site and samples were taken as close as possible to the damage.

Dietary habits of grouse also show seasonal and regional variations, but there is general consistency in the literature that northern grouse favour aspen leaves and buds over those of all other trees (Svoboda and Gullion 1972; Doerr, et al. 1974); willow is also taken when available. Rose and Parker (1983), reported Northern Ontario grouse had much aspen material in their crops at two sites in the two seasons studied. Other food items, including arthropods, horsetails, and fungal tissue accounted for a substantial proportion of the gut content (> 50 % dry weight and > 60 % by frequency of crop contents in the case of fungi) of birds from one collection site.

Although beaver may remain in the vicinity of their native colony most of their lives, wholesale movements of groups of beaver and dispersal of young adults occur (Hill 1982). Travel of 200 km or more has been reported for some tagged and released beaver, but dispersal (especially of two-year olds) is usually less than 16 km in a straight line (Jenkins and Busher 1979).

Movements of grouse, studied by banding nestlings and subsequent recovery of them when older, start in the fall when family groups disperse. Exceptionally, dispersal movement up to 19.2 km has been reported, but 75 % of marked birds travel less than 1.6 km from the point of banding (Hale and Dorney 1963). Adult grouse are more sedentary than younger birds and females are more mobile than males (Archibald 1976; Godfrey 1975; Chambers and Sharp 1958; Hale and Dorney 1963; and Gullion and Marshall 1968).

The importance of knowledge of beaver and grouse movement is that animals reported on in this study may have moved a considerable distance in their lives and were not necessarily long-term residents at their places of capture.

METHODS AND MATERIALS

areas

All investigation took place in the Sudbury-North Bay and Timagami sections (L.4e, L.9) of the Great Lakes - St. Lawrence Forest Region of Canada (Rowe 1959). This part of Ontario has numerous rivers and lakes situated among rugged outcrops of Canadian Shield bedrock devoid of vegetation, and wet flats and lowlands of acidic podzols or calcareous soils variably covered with mixed hardwoods and conifers. Pioneer species (aspen, ***Populus tremuloides,*** and white birch, ***Betula papyrifera***) predominate and limited numbers of tolerant forms such as sugar maple (***Acer saccharum***) and yellow birch (***Betula lutea***) are to be found. Red, white, and jack pine (***Pinus resinosa, P. strobus,*** and ***P. banksiana***), balsam fir (***Abies balsamea***), black spruce (***Picea mariana***), and white spruce (***P. glauca***) are scattered through the forest.

Study areas in the Serpent River drainage were three in number: **a) 'Elliot Lake'**, a triangular area with points at Ten Mile Lake to the Northwest, Rochester Lake in the Northeast, and Nordic Lake to the South, contains the Town of Elliot Lake, U tailings deposits, and several lakes and waterways. Substantial variation in ^{226}**Ra** concentration in these water bodies has been reported (see below). **b) 'Mid-Serpent'**, the watercourse down-stream from the river's exit from Quirke Lake, contains Bear, Whiskey, and Pecors Lakes. Land adjacent to this stretch of the river, unpopulated except for fishing camps, contains several registered traplines. **c) 'Low-Serpent'**, the lower reach of the river, below its exit from Pecors Lake, passes through the territory of the Serpent River Indian Band, whose members trap along it, before emptying into the North Channel of Lake Huron.

Control areas were at two locations: **a) 'Control-local'**, encompassing

Tweedle, Sagard, and Poulin Townships, is located about 40 km NW of Elliot Lake, upwind and in a different watershed, was chosen because of accessibility, location, and lack of U industry operations. Occurrences high in **Th**-series radionuclides are known in this general area (W. Meyer, Resident Geologist, Ministry of Northern Development and Mines, Government of Ontario, Sudbury; personal communication). **b)** The second, **'Control-distant'**, 40 km NE of Sudbury and more than 130 km E of Elliot Lake, contains Lakes Wanapitei, Boot, Rathbun, Portage, and Matagamasi, and was chosen for its remoteness from Elliot Lake and its ease of access. Several U occurrences have been reported in the area, but none have been developed (W. Meyer; personal communication).

Water quality records of the Ministry of the Environment of the Province of Ontario (MOE) (MOE 1981, 1982, 1987) indicate substantial variation in ^{226}**Ra** concentration from place to place and over time at MOE sample stations in the vicinity of Elliot Lake. Each water sampling station within the study area at Elliot Lake was assigned to one of three classes based on the average radionuclide levels of water sampled at each station. The average total ^{226}**Ra** concentration at each station was calculated by summing all total ^{226}**Ra** water values for the years 1984 to 1987 and dividing by the number of samples. Only filtered ^{226}**Ra** values were available prior to 1984; these values were not used in this study. Site classes within the study area were defined as follows:

Elliot Lake-high, with ^{226}**Ra** levels $\geq$ 148 mBq.l^{-1} (included are all tailings deposits and portions of the Serpent River below an effluent discharge site at the Quirke mine waste management area).

Elliot Lake-medium, with ^{226}**Ra** levels from 75 to 147 mBq.l^{-1} (included Quirke, Nordic and North Nordic lakes).

Elliot Lake-low, with ^{226}**Ra** levels $\leq$ 74 mBq.l^{-1} (included Dunlop and Elliot Lakes).

Beaver trapped within the Elliot Lake area were assigned to an MOE water

sampling station, and a corresponding site class, as follows: The location of capture of each animal was recorded on a map indicating the locations of MOE water sampling stations (with their associated average total ^{226}Ra concentrations), and water flow vectors. Animals collected close to an MOE water sampling station were assigned to that station and subsequently included in the appropriate site class (-high, -medium, or -low) corresponding to its average total ^{226}Ra water value. An animal taken at a location receiving water passing two MOE sample stations was assigned an average water quality value calculated using all sample data available for both MOE stations. Specimens from areas without sampling stations were assigned to the closest MOE station down-stream in the water course.

animal specimens

numbers

Because tissue levels were expected to vary from animal to animal, a goal of ten or more beaver and grouse specimens was set as the sample size (n) at each location studied. Measures were made of ^{226}Ra levels in muscle, bone, kidney, liver, and gut content of each animal. As information was available on radionuclides in water and vegetation of the study areas, estimates were restricted to four water samples and four samples of plants used by the animals for food in each area. Estimations of total and dissolved ^{226}Ra in the water samples were made. Ra-226 levels in aliquots of vegetation samples (pooled by species), were measured.

collecting

Beaver carcasses were purchased from registered trappers. Most specimens were taken in season as part of the fur harvest, others were removed as 'nuisance' animals at other times of the year. The Elliot Lake area was sampled from Fall 1985 through late winter of 1988; Mid-Serpent and and Low-Serpent collections were made in the 1987-1988 winter. Control samples of beaver were taken in the spring of 1986. Grouse, purchased from hunters, were harvested from September 1987 through late winter 1988. Animal

samples were labeled as received and their source indicated on a master map.

processing: measurement, dissection, and tissue separation

Beaver carcasses, usually received frozen and intact except for fur (removed for sale) and tails (snapped off inadvertently in several cases) were weighed to 1 g on an OHAUS™ heavy duty balance, and then thawed. The skull was removed and preserved for later use in age assessment. Carcasses were dissected, sexed by examination of reproductive organs, and samples of the liver, both kidneys, spleen, the right hind leg (for muscles and bone), and chyme (stomach contents), were removed and separately bagged and frozen for later study. The right femur of each beaver was prepared by removing most muscle (with scissors) then placing it (in a sealed plastic bag) in boiling water for 1 h to facilitate removal of the remaining adherent tissue by scraping with a scalpel.

Grouse carcasses, also received frozen, were mostly intact except for several lacking the pectoralis (flight / breast) muscles, which had been removed for eating, or internal organs due to evisceration. Specimens were thawed and weighed. Dissection, inspection and removal of internal organs, and sexing, followed. Samples of pectoralis or leg muscle tissue, the liver, both kidneys and the hind legs (for muscles and bone) were separately bagged and frozen for later study. Bones of the hind legs were prepared in a similar manner to that employed for beaver femurs. In the case of incomplete specimens of grouse, the sternum and furcula were analysed in place of limb bones.

aging

Beaver were aged to one of five classes on molar and premolar teeth eruption, the degree of closure of basal openings, and molar fluting. Age categories and criteria were (after van Nostrand and Stephenson 1964): 0.5 to 1.0 year - primary premolar, if present, forming a cap over the permanent premolar. Crown of the emerging premolar below that of the first molar; 1.5 to 2.0 years - single large opening present in the base of each of the four cheek teeth, some advanced cases with partial constriction of the openings; 2.5 to 3.0 years - basal opening of first molar markedly restricted and in some

specimens may appear to be closed, basal cavity of the premolar typically has two openings, while the second and third molars each have one small restricted basal opening; 3.5 to 4.0 years - opening of the basal cavity of the first molar is usually closed, basal openings in the other cheek teeth usually conspicuous although well constricted (animals of age categories 2.5 to 3.0 y and 3.5 to 4.0 y were pooled for this study forming age class 2.5 to 4.0 y); 4.5 y and older - basal cavities of all the cheek teeth usually completely closed by 4.5 y. Aging of beaver beyond 5 y, which requires examination of annual layers in cementum, was not performed in this study.

Grouse were aged as immature (I), aged under 1 y, and adult (A), aged 1 y or more, on the basis of replacement and growth of the primary and secondary flight feathers of the right wing (Hale et al. 1954). In adults primary flight feathers 8, 9, and 10 are rounded with sheathing at the base of the feather; immature birds have primary flight feather 8 rounded at the tip and sheathing is present at the base, but primaries 9 and 10 are pointed and lack sheathing (ruffed grouse only molt through primary 8 in their first fall).

plant specimens

collecting

Woody plant material was collected from Elliot Lake, Mid-, and Low-Serpent areas between the 27th August and the 15th September 1987. Plant material was taken within 15 m of high water mark of the Serpent River or Whiskey Lake, usually where signs of beaver clipping and damage were seen and close to places where animals had been trapped or shot. Collections from the Control-distant area were made on the eastern shore of Lake Wanapitei on the 19th October 1987.

Fungi (mushrooms and toadstools) were collected in winter 1987-1988 from decaying tree trunks at: Elliot Lake (Stanrock Mine turnoff, 50 m East of Hwy. 108) on the 16th November; Mid-Serpent (Whiskey Lake, east shore) on the 1st October; and, Low-Serpent (Intersection of Hwy. 17 and the Serpent River) on the 7th November . Control samples were taken on the eastern shore of Lake Wanapitei on the 5th April.

Fungal samples were brought frozen to the laboratory where they were identified and stored dry until analysis.

processing

Branches with leaves (and buds, flowers, and fruit if present) were collected from woody plants in each area. On return to the laboratory, field identifications were confirmed, and fresh material was partitioned, as appropriate, into stem and leaf (including petioles) samples. Ten 10 x 1 cm pieces of branch and up to 500 g of leaves were pooled from several plants of the same species and allowed to air dry in paper bags pending further analysis. Some stems and leaves were analysed as received, others were washed gently under running water in the laboratory to remove adherent material, prior to analysis. All plant samples were labeled on receipt and their source marked on a master map.

water samples

collecting

Water was collected as follows: **a)** Elliot Lake samples were taken at the bridge over the Serpent River, near the Panel mine collecting location of beaver captures, at 1400 h on the 28th August 1987; analysis of total and dissolved ^{226}**Ra** in these samples started at 1500 h of the same day. **b)** Mid-Serpent samples were collected from the east shore of Whiskey Lake at 1200 h, also on 28th August 1987; analysis of their total and dissolved ^{226}**Ra** similarly started at 1500 h on the same day. **c)** Low-Serpent samples were collected from the intersection of the Serpent River and Hwy. 17 at 1300 h on 27th August 1987, and from the Serpent River at the Serpent River Village (in the vicinity of the derelict 'Atomic Drive In' movie theatre) at 1400 h on the same day; analyses of total and dissolved ^{226}**Ra** in these samples started at 1500 h on the day collected. **d)** Control - distant samples, obtained from the eastern shore of Lake Wanapitei at 0800 h on the 6th November 1987, were kept at 2-5 °C during transport to the laboratory to limit biological activity causing uptake or release of ^{226}**Ra** by organisms contained in the samples;

radiological analyses of these samples started at 1230 h on the day of collection.

Water samples (4 x 1 l from all locations except Low-Serpent which provided 8 l, in two collections, taken at the locations just described) were taken in acid-washed, triple-rinsed 1 l plastic bottles 30 cm beneath lake or river surfaces in places where animals had been captured. Analyses started within hours of collection: 2 l were analysed for dissolved ^{226}Ra after filtration and 2 l were analysed for total ^{226}Ra content after acidification with 10 ml 1N HCl. Water samples were tagged on receipt and their point of origin marked on a master map.

analytical methods

glassware

All glasswares, porcelain crucibles, and lids were cleaned by washing in an industrial detergent (Alconox™ or Sparkleen™), rinsing in distilled water and soaking for 24 h in 50 % HCl. On removal from the acid bath, glassware was rinsed three times in distilled water and then placed in a drying oven at 70 to 80 °C. Crucibles and lids were cooled in desiccators then weighed and placed into a drying oven; drying and weighing continued until constant weights were recorded (to 0.01 g).

animal tissue processing

After being weighed fresh, tissues were placed into porcelain crucibles (prepared as described above); beaver bones were broken with a hammer to allow the entire sample to be fitted into the crucible, and to facilitate drying of marrow. Tissues were then dried to constant weight at 70 to 80 °C. Ashing was done in a muffle furnace (Lab Heat Muffle Furnace™, Blue M Electric Co., Model No. M25a-1a) by raising the temperature to 500 °C over 6 h; maximum temperature was maintained for 24 h. Samples were cooled to room temperature (≈ 25 °C), wetted with NH_4NO_3 (30 %), and oven dried at 70 °C overnight. Ashing was repeated for 24 h if signs of carbon remained after the first processing. Ashes were crushed, using small pestles, then placed into glass beakers for complete digestion by 30 % HCl while being stirred on a hot plate at 70 °C. The quantity

of 30 % HCl used depended on the quantity of tissue ashed. Digested samples were diluted to 1l with distilled water stored in plastic bottles until analysed.

plant tissue processing

Plant tissues were air-dried, then aliquots (unwashed or rinsed gently in water to remove particles) were placed in individual porcelain crucibles (prepared as described above) and dried at 70 to 80 °C to constant weight as described for animal tissues. Dry-ashing and digestions were conducted as for animal tissues except silica inclusions required treatment with strong acid mixtures to ensure solution in several cases.

water

Half the water samples were analysed as collected, the others were filtered to remove particulates, within hours of collection.

analysis of ^{226}Ra

Measurement of ^{226}Ra in duplicate solution samples was by the alpha-spectroscopic method of Lim and Davé (1981): the 4.78 MeV alpha-decay peak of ^{226}Ra was counted following precipitation of Ra-Ba sulphate. A ^{133}Ba tracer solution, added to starting solid samples, allowed measurement (and appropriate correction for) the overall analytical recovery for ^{226}Ra analysis. Recovery rates of 80 % or more of the amount of ^{133}Ba added by spiking were customary in the study.

analysis of other radionuclides

Duplicate 1 g (approx.) samples of dried bone, muscle, and liver from two beaver and two grouse were sent for radionuclide measurement to the laboratories of Atomic Energy of Canada Limited (AECL), Kanata (neutron activation analysis) and Monenco Science and Technology (MONENCO), Calgary (chemical separation and alpha spectroscopy). AECL reported results of neutron activation analyses of U-238 and ^{232}Th (delayed neutron counting) in ppm, with threshold values at 1 ppm. MONENCO reported values in mBq.g^{-1} with threshold values at 5 mBq.g^{-1} for ^{226}Ra, ^{232}Th, ^{230}Th, ^{228}Th, and ^{210}Po, and 50 mBq.g^{-1} for ^{210}Pb. In the case of ^{210}Pb, analysis was performed by

measurement of its daughter, ^{210}Po, after 42 d in-growth to the samples.

quality assurance.

Several approaches assure the reliability of the ^{226}Ra data reported here. First, analyses were carried out in the laboratories of CANMET, Elliot Lake, where routine procedure involves calibration of the analytical system itself by certified NBS calibration standards. Second, the standard method, involving recovery of the gamma emitter (^{133}Ba) added to samples prior to digestions to measure analytic recovery of the radiological procedure, when applied to samples of cow shank bone (NBS material) spiked with known amounts of ^{226}Ra and ^{133}Ba, showed a recovery rate of 98 ± 10 %. Third, the Quality Assurance Programme of the CANMET Laboratory has the following checks made as a matter of routine: a) Certified CANMET tailings samples DL-1 and DL-2 are analysed. b) Standards and blanks are analysed along with samples. c) Cross-checks on liquid, solid, and biological sample measurements by CANMET are carried out by MONENCO Analytical Laboratories (Calgary). These three checks indicated variation was ≤ 10 %

The following were added as part of the current study. First, two fragments of each of two beaver bones were analysed at separate times (see results section). Second, two fragments of each of two beaver bones and two grouse bones were analysed independently (blind) by MONENCO Analytical Laboratories of Calgary, and CANMET (see results section).

data

statistics and transformations

As it was suspected that the data were unlikely to be normally distributed, nonparametric tests were performed for initial examination of differences among groups of animals divided by sex and age. Mann-Whitney U tests (two-tailed) were used to compare pairs of subgroups. Significance was indicated ($P < 0.05$) when $U_{calculated} > U_{table}$, (alpha = 0.05) (Sokal and Rohlf 1979). Kruskal-Wallis tests were employed for comparisons among three or more subgroups. Significance was indicated ($P < 0.05$) when

$K_{calculated} > X^2_{table}$ (alpha = 0.05) (Lapin 1975).

Statistical analyses started with groups subdivided by what was considered the least significant variable: sex. When no significant differences were found at the 5 % level, sex categories were pooled, and data reanalysed in age categories. Pooling of age classes was also found to be appropriate, as no significance among age classes emerged. Testing was not applied to subsamples of the beaver taken in Control-local and Control-distant areas owing to their small sample sizes. Seasonal variations could not be tested due to gaps in the data and to smallness of sample sizes when all subdivisions were made. Establishment of a hierarchy of importance for variables allowed focus on the principle objective of this study: comparison of radionuclide concentrations in animals from different locations.

The extensive datasets on ^{226}Ra in bone of beaver from sites in the Experimental area (Experimental-high, -medium, and -low) and Control-local and -distant areas, were tested for normality using Chi square (X^2) goodness-of-fit tests (Zar 1974). The tests indicated that assumptions of an underlying normal distribution were not warranted in all subsets of crude data (see APPENDIX V). Data were log-transformed (log_{10}), in an attempt to normalize the data. The tests, when repeated, showed that normality had been approached to the degree that parametric statistical testing became appropriate (APPENDIX V).

Differences among site categories and areas were tested at the 5 % level using a one-way analysis of variance (ANOVA) on the log-transformed data. Duncan's new multiple range test, with Kramer's procedure to allow for unequal sample size, was applied to reveal significant differences among groups (Steel and Torrie 1980).

presentation and calculations

To facilitate comparisons with the findings of other workers, values are expressed throughout this report as $mBq.g^{-1}$ dry weight of plant or animal tissue and $mBq.l^{-1}$ of water, except in calculation of concentration ratios, where use of values based

on wet or fresh weight, and $mBq.g^{-1}$ of water, is called for by convention.

Graphical presentations are of back-transformed data. Sample means and their associated standard errors were antilogged to ensure that units on the vertical axis are familiar; this process accounts for error bars appearing asymmetric in some cases.

concentration ratios

When calculating the ^{226}Ra concentration ratio (f_{le}), the following formula (after ICRP 1978), was employed:

$$f_{le} = X_l / X_e$$

where X_l = radionuclide concentration in animal tissue ($mBq.g^{-1}$ wet weight)

and X_e = radionuclide concentration in water ($mBq.l^{-3}$) or vegetation ($mBq.g^{-1}$ wet weight)

Mean animal tissue and gut content ^{226}Ra concentrations were calculated on log-transformed data and concentration ratios were based on their back-transformed values. For these calculations radionuclide concentrations were expressed as $mBq.g^{-1}$ wet weight as required by the standard formula. Radionuclide concentration in diet items needed to be calculated as the level at the time of consumption. This presented a problem since moisture content of vegetation varies with time of day and season due to water stress (Wilson et al. 1953; Boyer 1968), and with changes resulting from absorption or loss of water after removal from the living tree. Particularly troublesome is the habit beaver have of felling trees and consuming them after a delay which may range from minutes to months. During

this time, leaves and branches may lose or gain water by evaporation or absorption if left exposed on the bank, or may take up water during storage in floating caches until eaten during winter. Tissue moisture is also lost in varying amounts due to differences in handling, and the time and method of sample storage prior to analysis.

To reduce variation attributable to variation in moisture content, values for vegetation samples, originally expressed as $mBq.g^{-1}$ dry weight, were adjusted to standard moisture contents. In a study of moisture in leaves picked in the vicinity of Sudbury, Ontario, in September, G.M. Courtin of Laurentian University (personal communication) observed the moisture content of aspen leaves to be 69.1 ± 1.67 %, n = 4, of their fresh weight, and that of birch leaves to be 72.6 ± 2.68 %, n = 4, of their fresh weight. Leaves left in protective net bags on the forest floor for 42 d absorbed water: 10.2 ± 8.39 % , n = 3, of their fresh weight in the case of aspen and 25.4 ± 3.49 %, n = 3, in the case of birch. In calculating radionuclide levels in leaves used as diet items in the present study, a value of 70 % moisture content was used as a standard value for woody plants.

In the case of stems, the following standard moisture contents were used as the basis for calculation: 48.5 % for aspen, 49.7 % for largetooth aspen, 58.2 % for willow, and 49.5 % for alder (Wangaard 1950). For white birch the value of 47.1 % was used. This value is midway between the 54.8 % moisture content reported in the same area for moose browse stems (MacLaren 1987) and 39.4 % reported for birch wood (Wangaard 1950).

As fungal material is eaten by grouse after being dried out by wind and sun in winter, the radionuclide level in air-dried material was used as the basis for calculation.

RESULTS and DISCUSSION

The numbers of specimens collected and processed are indicated in Table 1.

Table 1. Numbers of beaver and grouse specimens from study and control areas.

	beaver			grouse
	1986[a]	1987	total	1987
SITES				
Elliot Lake	-	10	**10**(10 bmlks)[b]	**9**(9 bmlkcsi)
-high	34	-	**34**(34 b)	-
-medium	29	-	**29**(29 b)	-
-low	57	-	**57**(57 b)	-
Mid Serpent	-	11	**11**(11 bmlks)	**7**(7 bmlk)
Low Serpent	-	15	**15**(15 bmlks)	**9**(7 bmlk)
Control - local	20	-	**20**(9 b)	**10**(8 bmlk)
Control - distant	18	-	**18**(18 b, 10 mlk)	**12**(12 bmlk)
Totals:			**194**	**47**

[a] includes four specimens taken in 1985

[b] in parentheses, figures indicate specimens processed; letters indicate tissues analysed (as available). Key: b = bone, m = muscle, l = liver, k = kidney, c = crop contents, s = chyme, i = chyle (intestine contents).

- samples not taken or processed

Kill locations of beaver and grouse taken in the basin are indicated in Figs. 1 and 2; date and place of capture, weight, estimated age, and tissue levels of ^{226}Ra of each beaver and grouse specimen are contained in APPENDICES I and II. Information on beaver and muskrat fetuses is contained in APPENDIX III.

Figure 1. Kill sites of beaver taken in the Serpent River drainage basin.

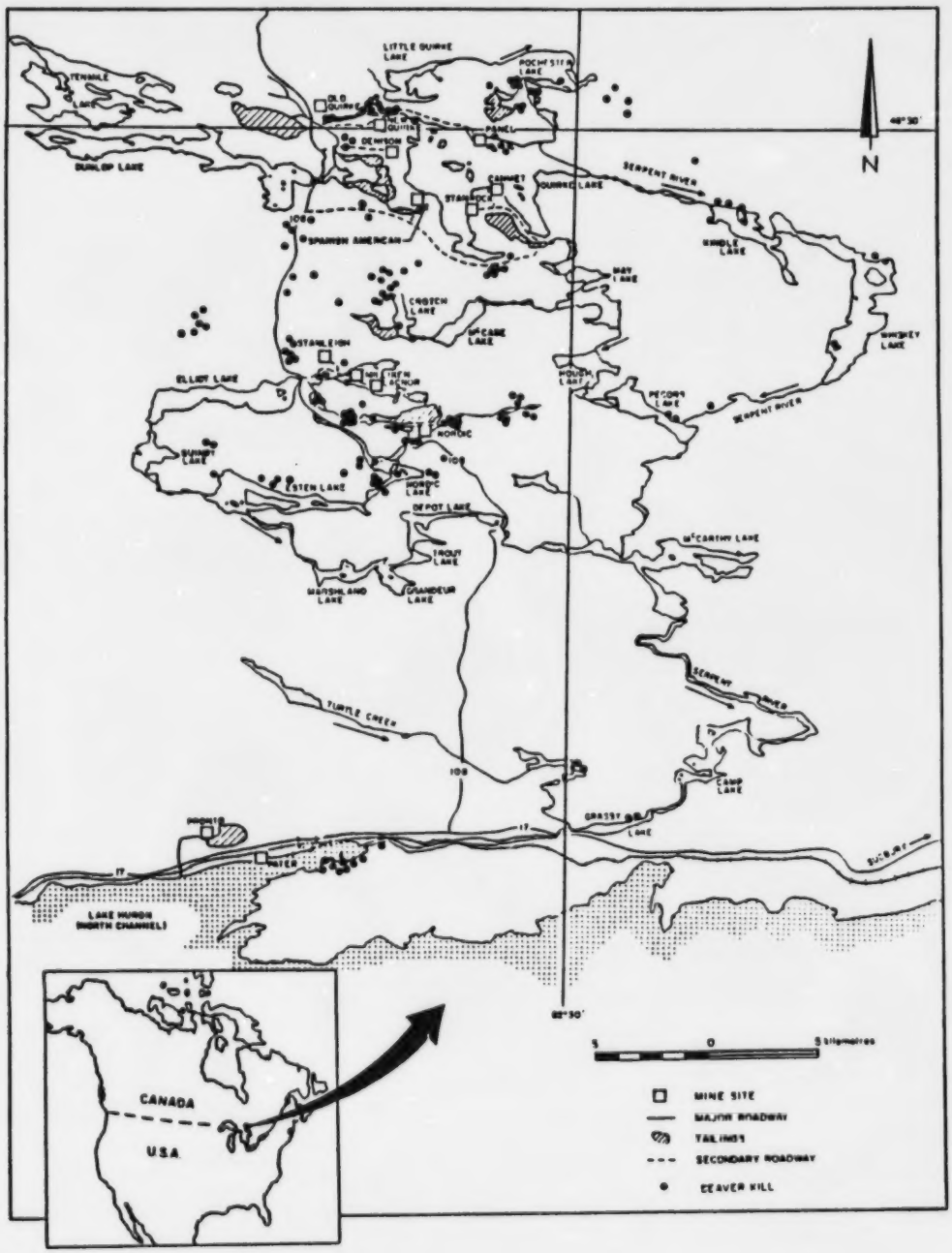
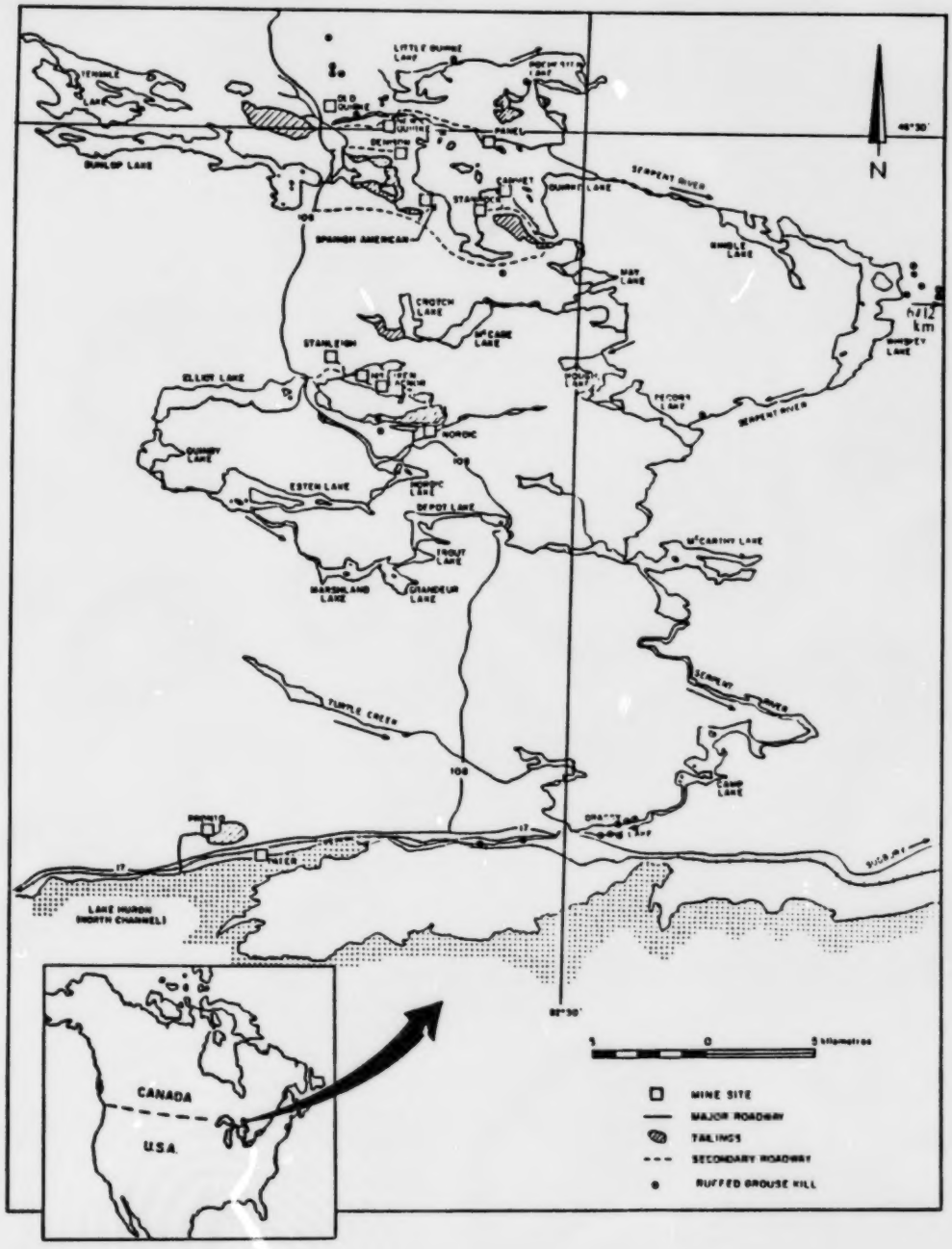


Figure 2. Kill sites of grouse taken in the Serpent River drainage basin.



The goal of $n \geq 10$ specimens per locality was surpassed in all beaver samples, matched in grouse control samples, and closely approached in other grouse samples. The slight shortfall in Elliot Lake, Mid-Serpent, and Low-Serpent locations reflects low population density of the birds in the area during the regular shooting season and the winter of 1987-1988.

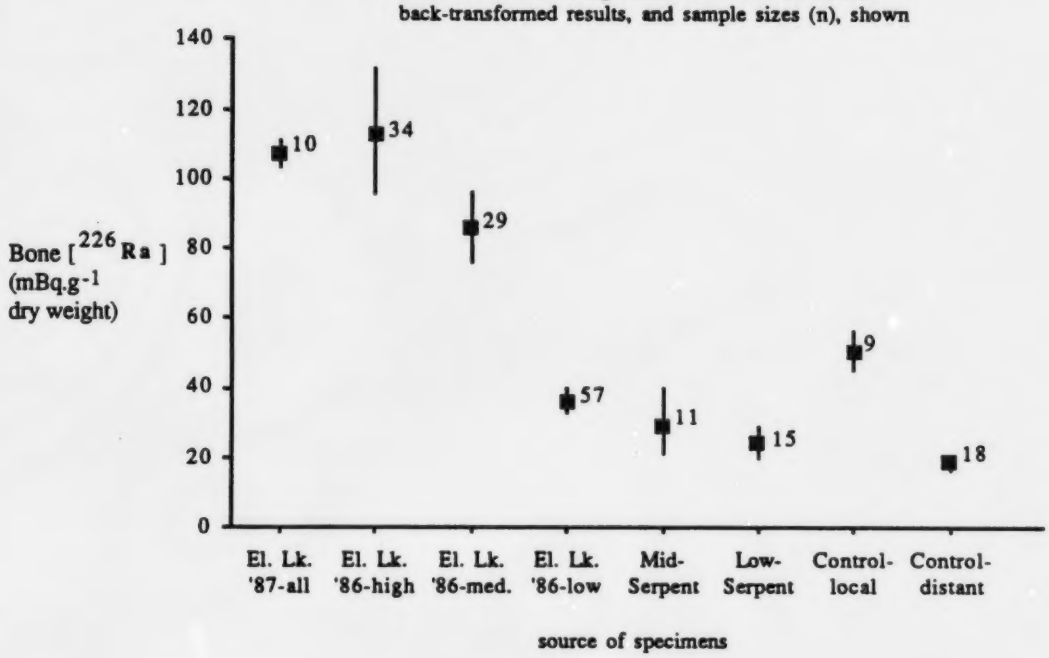
For reasons of economy, not all beaver and grouse tissue and gut content samples from all locations were analysed for radionuclides: All beaver (120) collected in the Experimental area in 1986, and half the Control-local animals (9) taken in 1986 were analysed only for their bone levels of ^{226}Ra; bone of all Control-distant beaver (18), but muscle, liver, and kidney tissues of only ten (10), were analysed; all tissues (and chyme) of all beaver taken in 1987 at Elliot Lake (10), Mid-Serpent (11), and Low-Serpent (15), were analysed. Bone, muscle, liver, and kidney ^{226}Ra, levels of most grouse specimens were measured, and in the Elliot Lake samples, the contents of the crop, chyme, and chyle (contents of the intestines) were analysed in addition. Not all tissues could be measured in all animals as some specimens were received incomplete or damaged.

Not only were differences among control and study sites tested for significance, but differences among subgroups of beaver, from sites in the Elliot Lake region with different levels of ^{226}Ra in the water, were examined. Information on ^{226}Ra values of tissues and chyme is summarized in Figures 3 to 7:

beaver - bone

Levels of ^{226}Ra in bone tissue of beaver taken from each site category and area are indicated in Figure 3:

Figure 3. Ra-226 in bone of beaver from study and control areas
means ± 1 SEM of log-transformed data calculated;
back-transformed results, and sample sizes (n), shown



ANOVA indicated significant difference(s) among the groups ($F_{7,175}$ = 18.90, $P < 0.0001$). Duncan's new multiple range test, with Kramer's modification, applied to the log-transformed values, produced the following outcome:

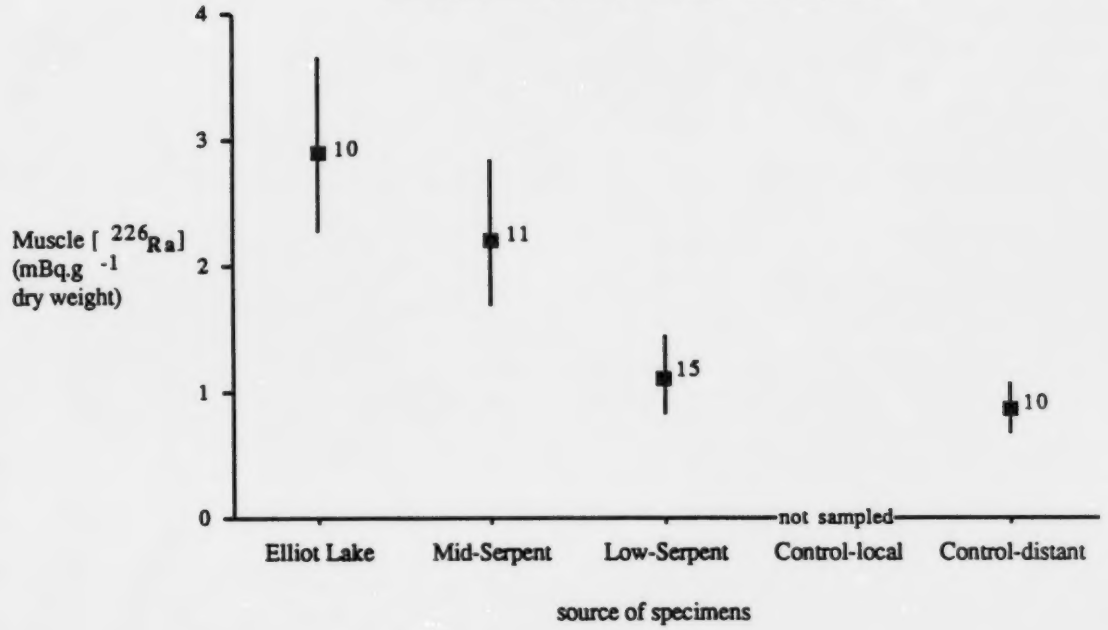
	Elliot Lake 1986 - high	Elliot Lake 1987 - all	Elliot Lake 1986 - med.	Control-local	Elliot Lake 1986 - low	Mid-Serpent	Low-Serpent	Control-distant
Mean [^{226}Ra] $mBq.g^{-1}$ =	112.7	107.2	85.5	50.6	36.0	29.0	24.2	18.8

(back-transformed means presented, those sharing same underline are not significantly different , $P \geq 0.05$)

beaver - muscle

Levels of ^{226}Ra in muscle tissue of beaver taken from each area are indicated in Figure 4:

Figure 4. Ra-226 in muscle of beaver from study and control areas
means ± 1 SEM of log-transformed data calculated;
back-transformed results, and sample sizes (n), shown



ANOVA indicated significant difference(s) among the groups ($F_{3,42} = 4.49$, $P < 0.01$). Duncan's new multiple range test, with Kramer's modification, applied to the log-transformed values, produced the following outcome:

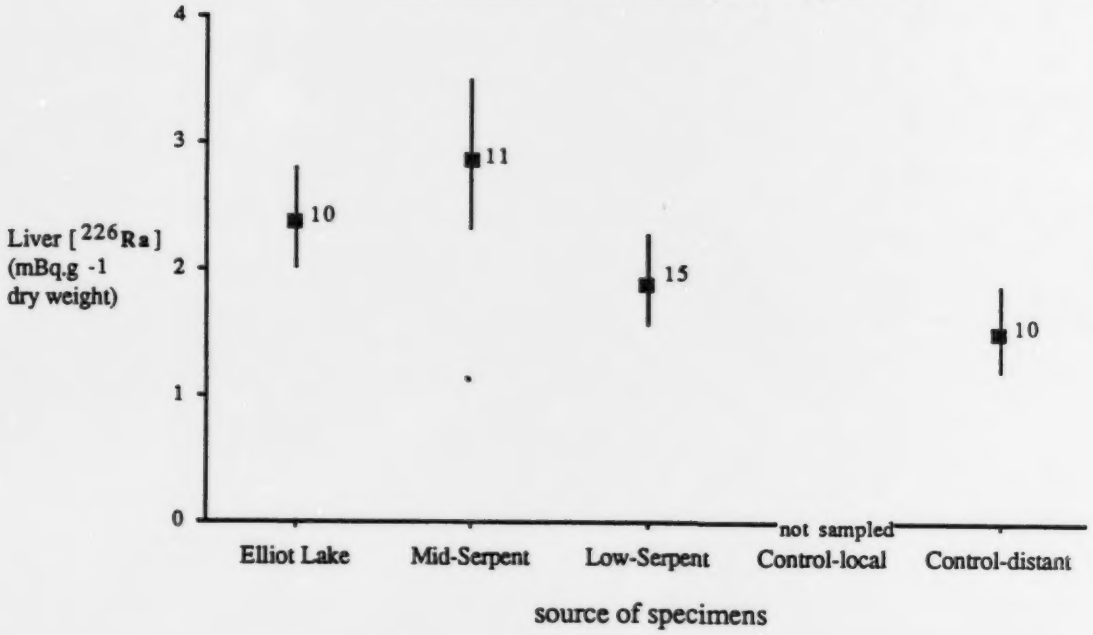
	Elliot Lake 1987 - all	Mid-Serpent	Low-Serpent	Control-distant
Mean [^{226}Ra] $mBq.g^{-1}$ =	2.9	2.2	1.1	0.9

(back-transformed means presented, those sharing same underline are not significantly different , $P \geq 0.05$)

beaver - liver

Levels of ^{226}Ra in liver tissue of beaver taken from each area are indicated in Figure 5:

Figure 5. Ra-226 in liver of beaver from study and control areas
means ± 1 s.e.m. of log-transformed data calculated;
back-transformed results, and sample sizes (n), shown

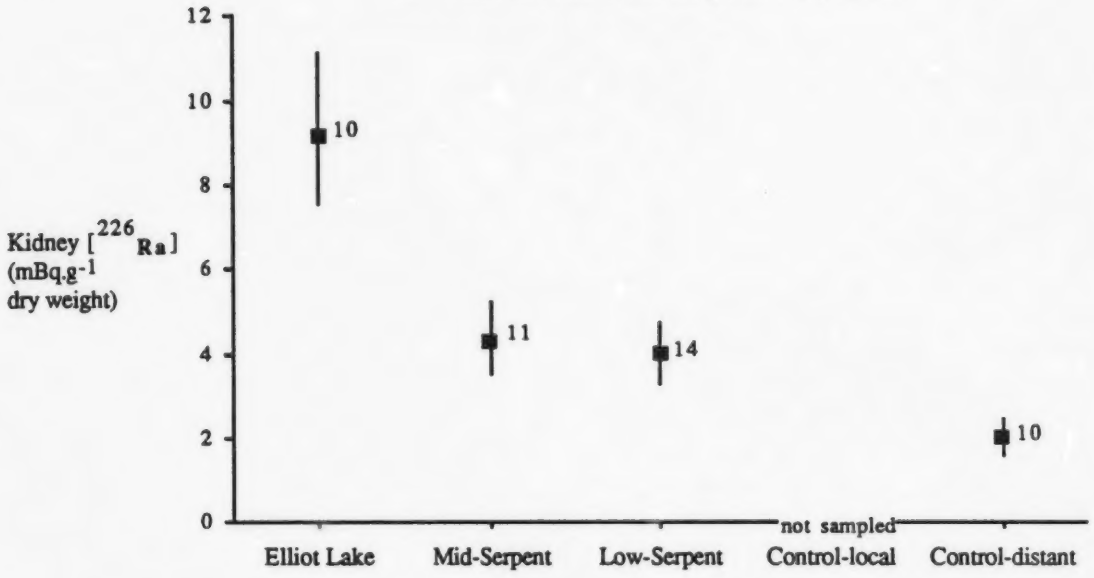


As analysis of variance of the log-transformed data failed to indicate any significant difference among the groups ($F_{3,42} = 1.88$, $P \geq 0.05$), no further analysis was carried out.

beaver - kidney

Levels of ^{226}Ra in kidney tissue of beaver taken from each area are indicated in Figure 6:

Figure 6. Ra-226 in kidney of beaver from study and control areas means ± 1 SEM of log-transformed data calculated; back-transformed results, and sample sizes (n), shown



ANOVA indicated significant difference(s) among the groups ($F_{3,41} = 8.61$, $P < 0.001$). Duncan's new multiple range test, with Kramer's modification, applied to the log-transformed values, produced the following outcome:

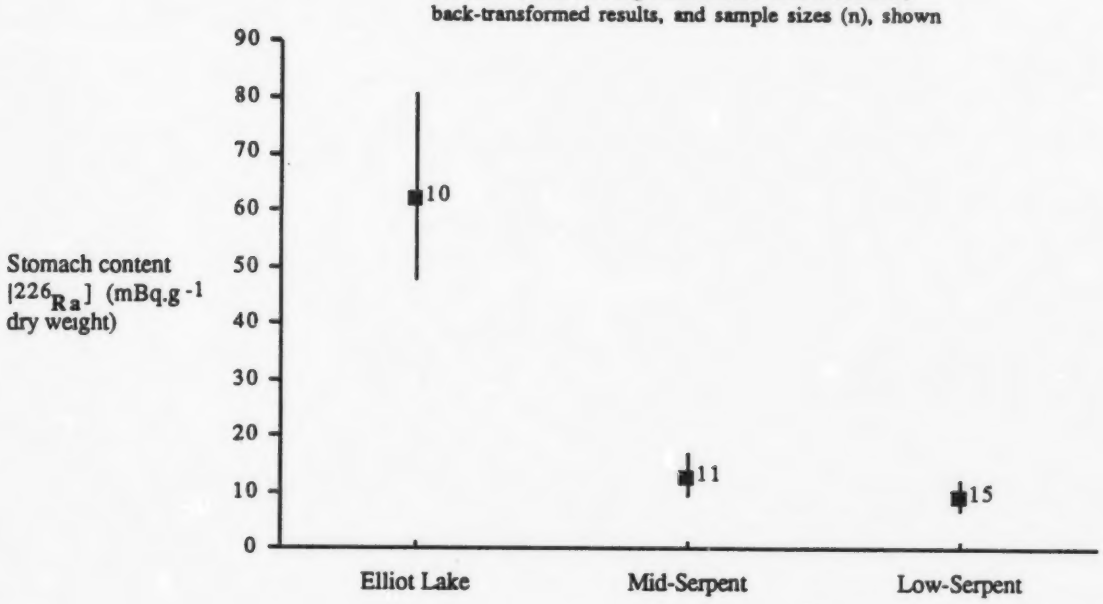
	Elliot Lake 1987 - all	Mid-Serpent	Low-Serpent	Control-distant
Mean [^{226}Ra] $mBq.g^{-1}$ =	9.2	4.3	4.0	2.0

(back-transformed means presented, those sharing same underline are not significantly different , $P \geq 0.05$)

beaver - chyme

Levels of ^{226}Ra in chyme of beaver taken from each area are indicated in Figure 7:

Figure 7. Ra-226 in chyme of beaver from study areas
means ± 1 SEM of log-transformed data calculated;
back-transformed results, and sample sizes (n), shown



ANOVA indicated significant difference(s) among the groups ($F_{2,33}$ = 11.65, $P < 0.005$). Duncan's new multiple range test, with Kramer's modification, applied to the log-transformed values, produced the following outcome:

	Elliot Lake 1987 - all	Mid-Serpent	Low-Serpent
Mean [^{226}Ra] $mBq.g^{-1}$ =	61.9	12.5	9.3

(back-transformed means presented, those sharing same underline are not significantly different , $P \geq 0.05$)

Significant variation in ^{226}Ra levels in beaver bone, muscle, and kidney are attributable to site. Bone of beaver collected in 1986, from Elliot Lake sites with historically high levels of ^{226}Ra in associated water bodies, and in 1987, had higher levels than local control animals and those from down-stream. Animals from sites in the Elliot Lake area with medium and low historical radionuclide levels, even though taken a short distance from others with significantly higher levels, and those from Mid-Serpent, did not differ from local controls. Bone from Elliot Lake-low, Mid- and Low-Serpent did not differ in their levels of ^{226}Ra, and Mid- and Low-Serpent did not differ from distant controls.

Levels of ^{226}Ra in muscle were higher in Elliot Lake and Mid-Serpent beaver than in distant controls; Low-Serpent animals did not differ from distant controls. The Elliot Lake mean value (2.9 $mBq.^{-1}$ dry tissue) is in the middle of the range reported by MacLaren (1978) for four beaver taken in the same area: 2.6 to 3.3 $mBq.^{-1}$. Variation in liver concentrations was not related to area or site of capture of the animals. Kidney levels of the radionuclide were higher in beaver taken at Elliot Lake than in those trapped down-stream; all study populations had significantly higher mean radionuclide levels in kidney tissue than was seen in distant controls.

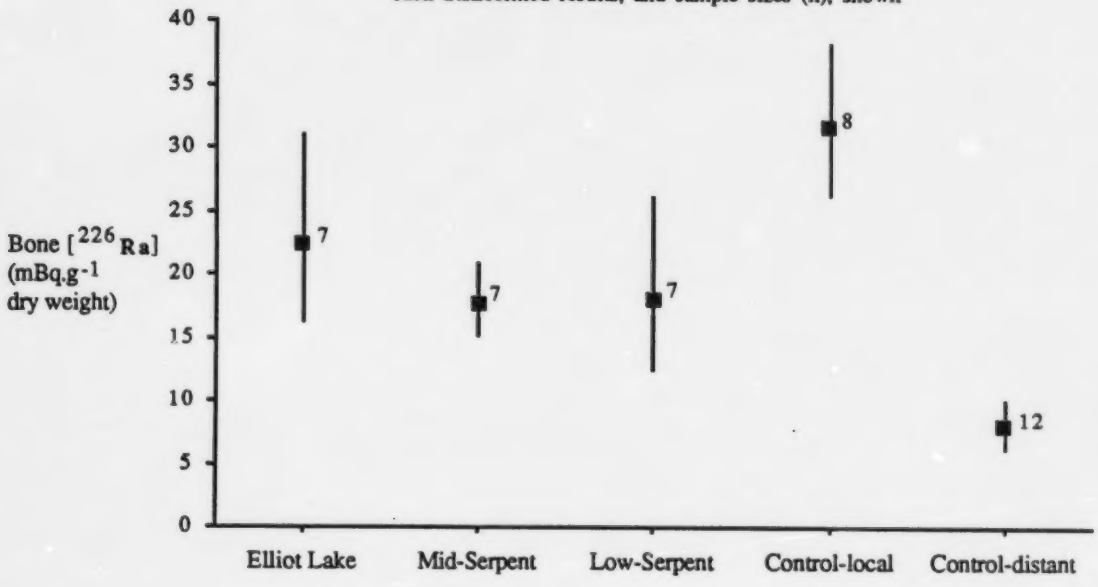
The variation seen in chyme values parallels closely the decrease in vegetation levels seen with increasing distance down-stream and away from Elliot Lake (see below).

Information on grouse tissue and gut content levels of ^{226}Ra is summarized in Figures 8 to 12.

grouse - bone

Levels of ^{226}Ra in bone tissue of grouse taken from each area are indicated in Figure 8:

Figure 8. Ra-226 in bone of grouse from study and control areas
means ± 1 SEM of log-transformed data calculated;
back-transformed results, and sample sizes (n), shown



ANOVA indicated significant difference(s) among the groups ($F_{4,36} = 4.58$, $P < 0.005$). Duncan's new multiple range test, with Kramer's modification, applied to the log-transformed values, produced the following outcome:

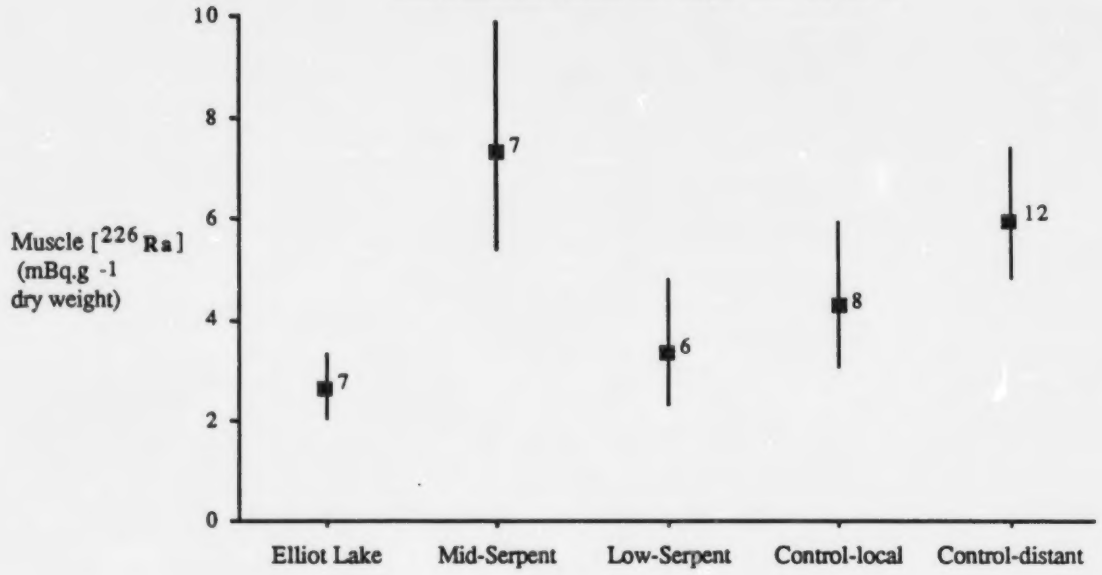
	Control-local	Elliot Lake	Low-Serpent	Mid-Serpent	Control-distant
Mean [^{226}Ra] $mBq.g^{-1}$ =	31.7	22.4	18.1	17.7	8.0

(back-transformed means presented, those sharing same underline are not significantly different , $P \geq 0.05$)

grouse - muscle

Levels of ^{226}Ra in muscle tissue of grouse taken from each area are indicated in Figure 9:

Figure 9. Ra-226 in muscle of grouse from study and control areas means ± 1 SEM of log-transformed data calculated; back-transformed results, and sample sizes (n), shown

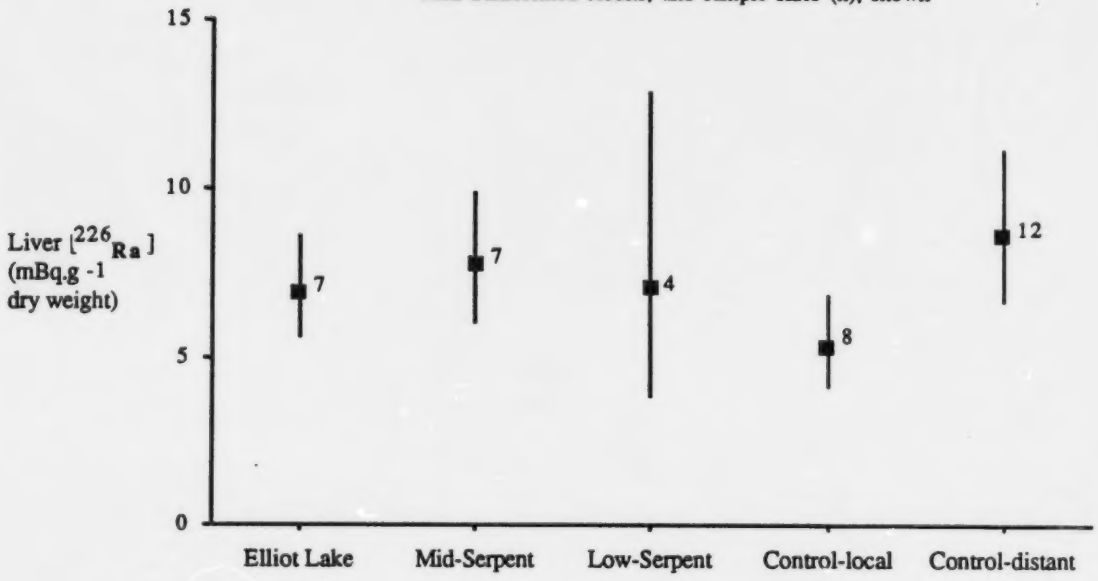


As analysis of variance on the log-transformed data failed to indicate any significant difference among the groups ($F_{4,35} = 2.02$, $P \geq 0.05$), no further analyses were carried out.

grouse - liver

Levels of ^{226}Ra in liver tissue of grouse taken from each area are indicated in Figure 10:

Figure 10. Ra-226 in liver of grouse from study and control areas
means ± 1 SEM of log-transformed data calculated;
back-transformed results, and sample sizes (n), shown

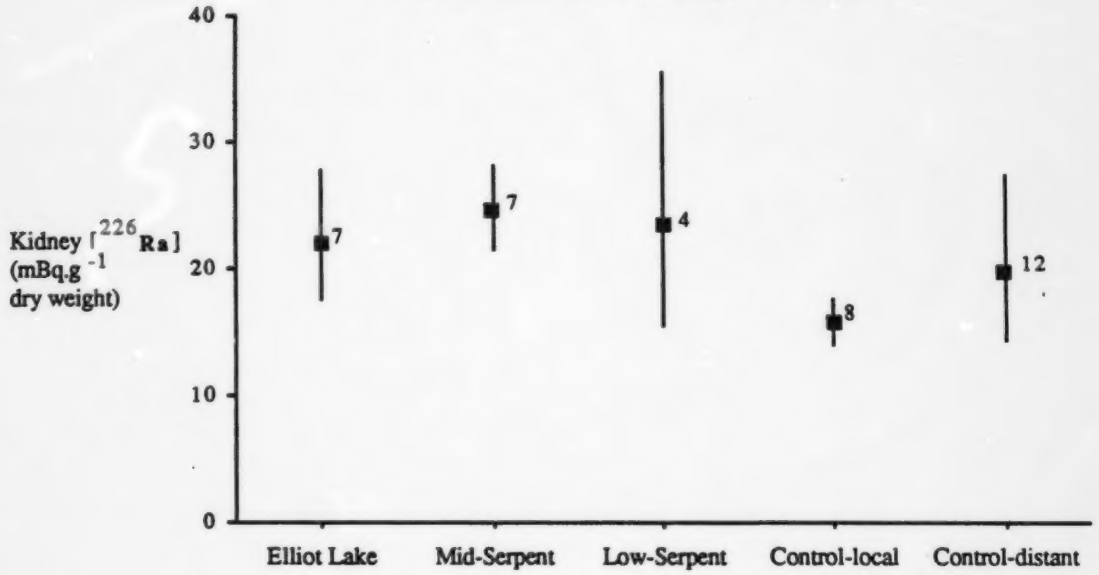


As analysis of variance on the log-transformed data failed to indicate any significant difference among the groups ($F_{4,33} = 1.26$, $P \geq 0.05$), no further analyses were carried out.

grouse - kidney

Levels of ^{226}Ra in kidney tissue of grouse taken from each area are indicated in Figure 11:

Figure 11. Ra-226 in kidney of grouse from study and control areas means ± 1 SEM of log-transformed data calculated; back-transformed results, and sample sizes (n), shown

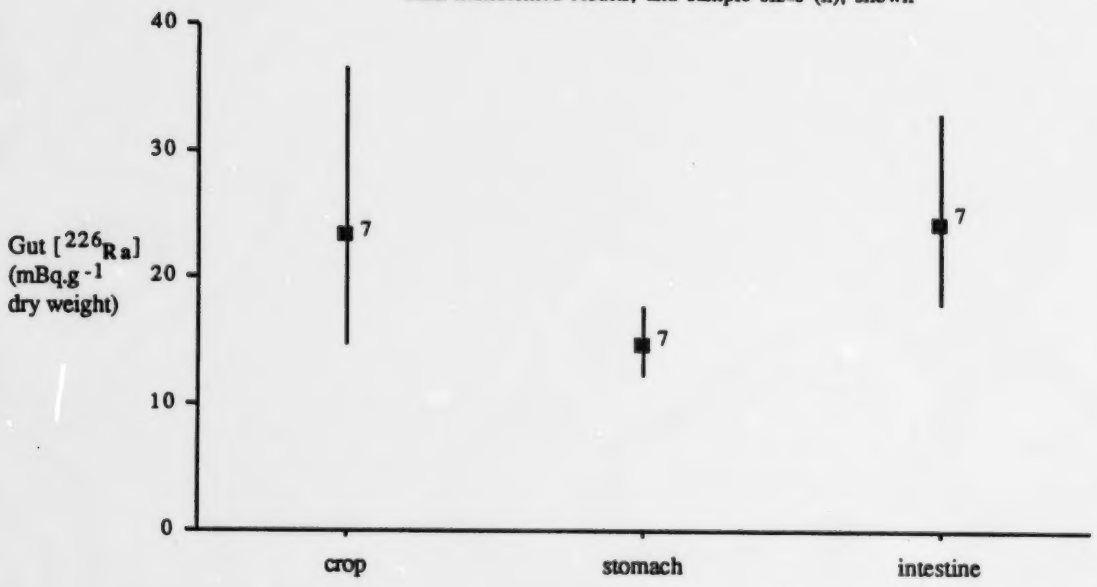


As analysis of variance on the log-transformed data failed to indicate any significant difference among the groups ($F_{4,34} = 0.73$, $P \geq 0.05$), no further analyses were carried out.

grouse - gut contents

Levels of ^{226}Ra in the crop, stomach, and intestine contents of grouse taken from the Elliot Lake and control areas are indicated in Figure 12:

Figure 12. Ra-226 in gut content of grouse from Elliot Lake area means ± 1 SEM of log-transformed data calculated; back-transformed results, and sample sizes (n), shown



As analysis of variance of log-transformed data failed to indicate any significant difference among the groups ($F_{2,18} = 0.72$, $P \geq 0.05$), no further analyses were carried out.

Grouse from the Serpent River drainage basin are not distinguishable, on the basis of their bone ^{226}Ra burdens, from those of local control areas. Birds from the study area, and from the local control area, did have more ^{226}Ra in their bones than those of the distant control area. Mean levels in muscle, liver, and kidney did not vary significantly by site. Ra-226 levels of 1.5 and 1.9 $mBq.g^{-1}$ dry weight of two grouse

muscle samples, and 1.1 to 4.1 mBq.g^{-1} dry weight in three duck muscle samples, were reported by MacLaren (1978) Gut contents of birds taken at Elliot Lake had levels similar to those of plant items eaten by the birds (see below); levels did not vary among crop content, chyme, or chyle samples.

maternal and fetal tissues

Levels of ^{226}Ra found in beaver and muskrat mothers, and their contained fetuses, are indicated in Table 2:

Table 2. Ra-226 in maternal and fetal tissues of beaver and muskrat[a] collected in the Serpent River drainage basin.

	[Ra-226] mBq.g^{-1}, dry weight of tissue				
	bone	muscle	liver	kidney	'residual'[b]
beaver					
WLC 4 - Mid-Serpent					
mother	28.4	3.6	3.9	4.6	-
fetuses (n = 4, **5.5** ± 0.60 g)	-	-	148.3±42.6	-	40.9±3.5
SRB 15 - Low Serpent					
mother	11.3	2.1	0.9	1.2	-
fetuses (n = 4, **21.9** ± 4.52 g)	-	-	108.4±24.8	-	39.1±17.5
SRB 14 - Low Serpent					
mother	7.1	0.1	2.7	2.5	-
fetuses (n = 6, **22.2** ± 2.21 g)	-	-	79.4±14.2	-	26.8±5.7
SRB 2 - Low-Serpent					
mother	2.2	1.0	2.0	2.3	-
fetuses (n = 3, **64.7** ± 3.18 g)	-	-	23.5±9.6	-	4.6±0.5
muskrat					
EM 104 - Elliot Lake ('high site)					
mother	530.3	-	-	-	-
fetuses (n = 6, **23.0** ± 0.37 g)	-	-	108.2±37.0[c]	-	21.9±1.7
EM 104 - Elliot Lake ('high site)					
mother	512.8	-	-	-	-
fetuses (n = 8, **22.1** ± 1.47 g)	-	-	137.2±61.9	-	10.0±1.2

[a] data on adult muskrats from Mirka 1988

[b] 'residual' tissues = fetus minus liver tissue

[c] one fetus liver lost in processing

- no sample

Levels of ^{226}Ra are ten to a hundred times higher in fetal beaver liver tissue than maternal liver, and are higher than those of the mother's bone. Liver has from three to five times the level of ^{226}Ra seen in the other tissues of beaver fetuses. Muskrat fetal liver tissue also shows an elevated level of ^{226}Ra, in comparison to other fetal tissues, but contains less than the mother's bone. An inverse relation between tissue ^{226}Ra levels and fetal size (and thus age) is suggested by the beaver data.

vegetation - woody plants

Levels of ^{226}Ra measured in woody plant samples are seen in Table 3:

Table 3. Ra-226 in woody plants from study and control areas.

[Ra-226] mBq.g^{-1} dry weight of tissue

	collection sites							
	Elliot Lake		Mid-Serpent		Low-Serpent		Control-dist.	
species	Leaves w(u)	Stems w(u)	Leaves w(u)	Stems w(u)	Leaves	Stems	Leaves	Stems
Trembling aspen *Populus tremuloides*	41.8(38.9)	68.9(55.6)	14.2(12.4)	11.0(9.0)	13.9	8.3	14.9	3.4
Largetooth aspen *Populus grandidentata*	52.7	98.7	-	-	3.7	4.7	-	-
Balsam poplar *Populus balsamifera*	34.8	32.0	-	-	-	-	-	-
White birch *Betula papyrifera*	252.2(268.0)	222.7(217.9)	16.2(12.3)	9.7(11.8)	76.8	29.0	46.0[a]	3.9
Willow *Salix sp.*	93.1	50.7	-	-	-	-	5.6	3.4
Speckled alder *Alnus rugosa*	99.7	135.7	[38.0]		-	-	-	-
Black ash *Fraxinus nigra*	-	-	39.1	35.2	130.3	89.8	-	-
Sweet gale *Myrica gale*	-	-	[12.3]		[99.3]		-	-
Wine berry *Ilex verticillata*	-	-	-	-	[171.6]		-	-

[a] sample small (<0.5g d.w.)
w washed, (u) unwashed
[ ] sample not partitioned
- samples not taken or processed

The ^{226}Ra levels in trembling aspen and white birch sampled from the

vicinity of tailings in the Elliot Lake area are similar to values reported previously in trees sampled on the tailings: Davé et al. (1985a) reported trembling aspen from the tailings with 33 ± 7 to 126 ± 11 mBq.g^{-1} dry weight in leaves and 70 ± 11 to 148 ± 15 mBq.g^{-1} dry weight in stems, and white birch with 222 ± 19 to 1,021 ± 37 and 130 ± 7 to 633 ± 37 mBq.g^{-1} dry weight of leaves and stems, respectively; Kalin (1988) found mean ^{226}Ra values of 96.2 and 92.5 mBq.g^{-1} in trembling aspen stems and leaves from several sites on the tailings, and 321.9 and 325.6 mBq.g^{-1} in white birch stems and leaves. Levels in stems of the same species from the Control-distant area generally agree with control values of Davé et al. (< 4 mBq.g^{-1} dry weight); the higher value seen in white birch leaves from the control area is attributed to the small sample weight, and is not considered further.

Values for ^{226}Ra levels in twigs of white birch (parts of the tree used as browse by moose) collected lower in the basin, recalculated as dry weight basis values from the ash weight data of MacLaren (1987), range from 7.4 to 23.4 mBq.g^{-1} (mean 14.1 ± 3.45, n = 4) in an area of collection corresponding to the Mid-Serpent section of the current study. Although their samples were taken some distance from the river course, their radionuclide burden is similar to levels seen in Table 3.

High values observed in white birch from Low-Serpent may reflect contamination of the trees or their habitat by silt from the river. Trees were sampled within 5 m of the river, from a low-lying area subject to flooding from time to time when the river overflows its banks during spring run-off, or at other times of high water. Serpent River sediments are rich in radionuclides (Hart and McKee 1985) and some of these particulates are probably resuspended during turbulence when the river is in spate. Levels seen in the speckled alder, black ash, sweet gale, and wine berry, all bush-sized plants growing in an area on the river bank subject to periodic flooding and all of which showed beaver clips, may have been similarly affected. Woody plant data generally agree with previously published values, and show a general decrease down-stream and in the control area.

vegetation - fungi

Levels of ^{226}Ra measured in fungal tissue samples are seen in Table 4. Fungal tissue levels, similar among species, tended to decrease with distance from the tailings. There are no published data to which these values might be compared.

Table 4. Ra-226 in fungi from study and control areas.

	[Ra-226] mBq.g^{-1} dry weight of fungus							
collection sites:	Elliot Lake		Mid-Serpent		Low-Serpent		Control-distant	
species	w	u	w	u	w	u	w	u
Amanita	-	-	1.0	4.4	-	-	-	-
Fomes	8.9	11.8	-	-	51.7	48.7	-	-
Hydnum	2.7	-	-	-	-	-	-	-
Polyporus	215.4	-	8.2	10.4	2.6	1.3	-	-
Stereum	71.1	78.8	-	-	-	-	-	-
Trametes	-	-	-	-	2.1	2.7	-	-
Trichaptum	-	-	-	-	6.4	6.7	-	-

w washed,
u unwashed
- samples not taken or processed

water

Levels of ^{226}Ra measured in water samples are seen in Table 5:

Table 5. Levels of ^{226}Ra in water samples from study and control areas

	[Ra-226] mBq.l^{-1} water[a]				
collection sites:	Elliot Lake	Mid-Serpent	Low-Serpent		Control-distant[b]
			Hwy 17 bridge	Drive-In theatre	
dissolved	118.1	122.4	95.1	80.1	12.1
total	558.7	192.0	232.0	358.7	9.0

[a] Average of two samples, each with duplicate subsamples.
[b] Difference between dissolved and total values is within analytic error limit of 3.7 mBq.

Total ^{226}Ra concentrations reported here for water taken from the Serpent River, and the lakes through which its passes, are higher than in moose drinking water sampled in the region and at a control site (range 5 - 60 $mBq.l^{-1}$, MacLaren, 1987). However, samples in that study were collected some distance from the Serpent River. Control-distant values are close to the limits of sensitivity of the analytic method employed and differences between total and filtered concentrations, and between our results and those for controls in studies in this area (5 $mBq.l^{-1}$, MacLaren 1987) and elsewhere (20 $mBq.l^{-1}$, Swanson 1985) are not considered important.

Total ^{226}Ra concentrations reported in Table 4 generally agree with others found in the Elliot Lake region. Most fall within the ranges reported by MOE for equivalent sites (see APPENDIX IV). The Elliot Lake sample, with 558.7 $mBq.l^{-1}$, corresponds to MOE site 014 which had a range of 80 - 610 $mBq.l^{-1}$ in the period from 1984 to 1987. The Mid-Serpent water, showing 192.0 $mBq.l^{-1}$, corresponds to MOE site 035 sampled once in 1984 and again in 1985 with a total ^{226}Ra concentration of 60 $mBq.l^{-1}$ found each time. However, water entering Whiskey Lake is the outflow of Quirke Lake with a range of 20 - 970 $mBq.l^{-1}$ from 1984 to 1987 as measured at MOE site 049. The Low-Serpent values of 232.0 and 358.7 $mBq.l^{-1}$ fall within the range for MOE site 001 of 30 - 600 $mBq.l^{-1}$.

Consonance of these data with others from the area, their general agreement with expectations for the area, and the decrease in ^{226}Ra concentrations with distance down-stream from tailings, leads to confidence in the reported values.

other radionuclides

Levels of other radionuclides, as reported by AECL and MONENCO, in tissues of two beaver and two grouse, are seen in Table 6; CANMET ^{226}Ra data are included for comparison:

Table 6. Radionuclides in tissues of beaver and grouse from Elliot Lake

[radionuclide] in tissues, dry weight basis)

	AECL		MONENCO						CANMET
	^{238}U	^{232}Th	^{232}Th	^{230}Th	^{228}Th	$^{210}Po^{a}$	^{210}Pb	^{226}Ra	^{226}Ra
	----- $\mu g.g^{-1}$ ----		---------- $mBq.g^{-1}$ ----------						
beaver:									
DSC 2									
bone	0.3	<1.0	<5.0	<5.0	10.0±5.0	70.0±10.0	90.0±30.0	90.0±10.0	123.0
muscle	<0.1	<1.0	<5.0	<5.0	<5.0	75.0±10.0	<50.0	-	2.1
liver	0.4	<1.0	<5.0	<5.0	<5.0	65.0±10.0	<50.0	-	2.6
DSC 8									
bone	0.1	<1.0	<5.0	<5.0	15.0±5.0	160.0±20.0	190±50.0	120±10.0	124.8
muscle	0.3	<1.0	<5.0	<5.0	<5.0	11.0±5.0	<50.0	-	4.9
liver	<0.1	<1.0	<5.0	<5.0	<5.0	35.0±5.0	<50.0	-	2.8
grouse:									
GEL 1									
bone	0.4	<1.0	<5.0	<5.0	<5.0	21.0±7.0	<50.0	10.0±5.0	150.2
muscle	0.2	<1.0	<5.0	<5.0	8.0±5.0	<5.0	<50.0	-	1.7
liver	0.2	<1.0	<5.0	<5.0	<5.0	15.0±5.0	<50.0	-	16.1
GEL 5									
bone	<0.1	<1.0	<5.0	<5.0	<5.0	24.0±5.0	<50.0	<5.0	20.8
muscle	<0.1	<1.0	<5.0	<5.0	<5.0	7.0±5.0	<50.0	-	6.0
liver	1.0	<1.0	<5.0	<5.0	<5.0	16.0±5.0	50.0±30.0	-	3.9

[a] measured 4th May 1988
- samples not taken or processed

Beaver muscle levels of ^{238}U indicated here (< 0.1 and 0.3 $\mu g.g^{-1}$ dry weight) compare to values previously reported in four beaver sampled in the same area (< 0.05, < 0.05, 0.07, and 0.08 $\mu g.g^{-1}$ dry weight) (MacLaren 1978). Levels of ^{232}Th, ^{230}Th, and ^{210}Pb in beaver muscle, were below detection limits in the same four beaver (MacLaren 1978), and in the two samples reported on here. In the case of grouse, muscle levels of ^{238}U presented in the table (< 0.1 and 0.2 $\mu g.g^{-1}$ dry weight) compare to values previously reported in two grouse taken from the Elliot Lake area (< 0.05 and 0.08 $\mu g.g^{-1}$ dry weight) (MacLaren 1978). Levels of ^{232}Th, ^{230}Th, and ^{210}Pb were below detection

limits in bone and muscle samples in this study and in muscle tissues examined by MacLaren (1978). As the ^{210}Po level is generally similar to the ^{210}Pb level in each beaver and grouse tissue examined (allowing for the analytic error) it was assumed that the radionuclides were in secular equilibrium; this obviated the need to adjust ^{210}Po values which had been measured several months after the death of specimens.

concentration ratios

Concentration ratios were calculated between diet items and tissue compartments of beaver taken from Elliot Lake (Table 7):

Table 7. Concentration ratios to tissue compartments of beaver from Elliot Lake.

		COMPARTMENT:	bone	muscle	liver	kidney
			^{226}Ra concentration ($mBq.g^{-1}$)[a]			
		X_1 =	67.5	0.8	0.7	2.3
COMPARTMENT		X_e = [Ra] ($mBq.g^{-1}$) dw	moisture %[b]	[Ra] ($mBq.g^{-1}$) ww	$f_{1e} = X_1/X_e$ (concentration ratios)			
trembling aspen	leaf	41.8	70.0	12.5	5.38	0.06	0.06	0.19
	stem	68.9	47.1	36.4	1.85	0.02	0.02	0.06
largetooth aspen	leaf	52.7	70.0	15.8	4.27	0.05	0.05	0.15
	stem	98.7	49.7	49.6	1.36	0.02	0.01	0.05
white birch	leaf	252.2	70.0	75.7	0.89	0.01	0.01	0.03
	stem	222.7	47.1	117.8	0.57	0.01	0.01	0.02
willow	leaf	93.1	70.0	27.9	2.42	0.03	0.03	0.08
	stem	50.7	58.2	21.2	3.19	0.04	0.03	0.11
alder	leaf	99.7	70.0	29.9	2.26	0.03	0.02	0.08
	stem	135.7	49.7	68.3	0.99	0.01	0.01	0.03
chyme				12.9	5.25	0.06	0.05	0.18
water				0.12[c]	572.05	6.73	6.15	19.88

[a] wet-weight basis, calculated on log-transformed values, back-transformed mean values presented
[b] see text
[c] $mBq.g^{-1} \approx mBq.l^{-3}$

Vegetation items and gut contents were taken as indicators of dietary levels; water was considered a component of diet.

The range in concentration ratios (vegetation to beaver tissues) can be restricted by calculating a single value for the ^{226}Ra content of beaver diet. Assuming a beaver eats equal parts of trembling aspen, largetooth aspen, white birch, and willow (alder being excluded as it is not a favoured species), and assuming that the amount of food material (biomass) from each plant is obtained in the ratio of 1 : 4 from the leaf and branch sections, then a weighted average concentration can be calculated taking into account the contributions of each species and component of that species. The value for ^{226}Ra in plant material calculated in this way is 51.6 $mBq.g^{-1}$ wet weight (the unweighted value is 44.6 $mBq.g^{-1}$ wet weight). The beaver chyme might be expected to have a level of radionuclide approximating the amount in the vegetation being eaten. The observed value was 12.9 $mBq.g^{-1}$ (n = 10), which is only about 25 % of that value. Part of the explanation for this difference may be the higher moisture content of chyme compared to that of vegetation: chyme is saturated with water and secretions and has a consistently high moisture content averaging 79.2 with a range from 75.7 to 82.32 % of fresh weight.

The desirability of working with values calculated on a dry weight basis is illustrated by the following: If values are calculated as in the last paragraph, but on a dry weight basis, then the average vegetation ^{226}Ra values are: unweighted 110.1 and weighted 110.2 $mBq.g^{-1}$ dry weight. The concentration of ^{226}Ra in the chyme calculated on the same basis is 61.9 $mBq.g^{-1}$ dry weight, which is closer than the agreement between wet weight based values.

Using the calculated vegetation value of 51.6 $mBq.g^{-1}$ wet weight, and the mean tissue levels in the table, then the concentration ratios are as follows:

bone / vegetation	67.5 / 51.6	=	1.31
muscle / vegetation	0.8 / 51.6	=	0.02
liver / vegetation	0.7 / 51.6	=	0.01
kidney / vegetation	2.3 / 51.6	=	0.04

Using dry-weight based values for stomach contents and beaver tissues concentration ratios are as follows:

bone / chyme	107.2 / 61.9	=	1.73
muscle / chyme	2.2 / 61.9	=	0.04
liver / chyme	2.38 / 61.9	=	0.04
kidney / chyme	9.2 / 61.9	=	0.15

Concentration ratios to grouse tissues are seen in Table 8:

Table 8. Concentration ratios to tissue compartments of grouse from Elliot Lake.

COMPARTMENT:			bone	muscle	liver	kidney
			^{226}Ra concentration (mBq.g^{-1})[a]			
		X_l =	13.0	0.7	2.2	6.2
COMPARTMENT	[Ra] (mBq.g^{-1}) dw	moisture %[b]	X_e = [Ra] (mBq.g^{-1}) ww	f_{le} = X_l/X_e (concentration ratios)			
trembling aspen leaf	41.8	70.0	12.5	1.04	0.06	0.18	0.50
largetooth aspenleaf	52.7	70.0	15.8	0.82	0.05	0.14	0.39
fungi			24.5[c]	0.53	0.03	0.09	0.25
crop contents			8.2	1.58	0.09	0.27	0.76
chyme			9.1	1.42	0.08	0.24	0.68
chyle			5.6	2.31	0.13	0.39	1.11
water			0.12[d]	110.06	6.06	18.83	52.84

[a] wet-weight basis, calculated on log-transformed values, back-transformed mean values presented
[b] see text
[c] air-dry basis (see text)
[d] mBq.g^{-1} = mBq.l^{-3}

Rose and Parker (1983) reported gut contents of grouse varied with season and site. In crops of animals collected in the fall, proportions of the contents (dry weight

basis) were as follows: aspen leaves from 15-60 %; fungi from 10-60 %; and various other materials to 30 % in aggregate. A typical diet, based on these observations, might have the following proportions: aspen leaves, 45 %, fungi, 45 %; other (including arthropods), 10 %. Rose and Parker reported blueberry leaves among the other items in the diet of these birds; these plants also occur in the area of Elliot Lake, and Davé et al. (1985b), have reported total ^{226}Ra contamination of berries varying from 20 to 290 mBq.g^{-1} dry weight within 500 m of tailings but declining to background levels of 2 to 6 mBq.g^{-1} dry weight at distances of 1 km or more down-wind from the tailings. About 17 % of the contamination was removed by rinsing in distilled water. Taking a value midway between the extremes (155 mBq.g^{-1} dry weight), removing 17 % (26.4 mBq.g^{-1} dry weight) to allow for adherent particulates, and converting the resulting value (128.7 mBq.g^{-1} dry weight) to a fresh weight basis value (assuming a moisture content of 70 %, Davé et al. 1985b) gives an estimate for fresh blueberries of 128.7 x 30 / 100 = 38.6 mBq.g^{-1} wet weight. If berry content is a reflection of the ^{226}Ra in the rest of the plant, and this is similar to the levels in other plants in the area, then we can use this value for the 10 % of the diet made up of plant and other materials. Although higher than aspen leaves, the value falls within the range for plant values reported in Table 3 (adjusted for moisture content).

In a diet with the components in the ratios just stated (45:45:10), with ^{226}Ra values of 12.5, 26.5, and 38.6 38.6 mBq.g^{-1} wet weight in washed aspen leaves, washed fungi, and washed other items, the weighted average level of ^{226}Ra is 21.4 mBq.g^{-1} wet weight. This value compares to the value of fresh crop contents (8.2 mBq.g^{-1} wet weight). When the vegetation value is considered with the mean tissue levels presented in Table 8, the following concentration ratios emerge:

bone / vegetation	13.0 / 21.4	=	0.61
muscle / vegetation	0.7 / 21.4	=	0.03
liver / vegetation	2.2 / 21.4	=	0.10
kidney / vegetation	6.2 / 21.4	=	0.29

Using dry-weight based concentrations, concentration ratios between crop contents and grouse tissues are as follows:

bone / crop contents	22.4 / 23.32	=	0.96
muscle / crop contents	2.61 / 23.32	=	0.11
liver / crop contents	6.92 / 23.32	=	0.30
kidney / crop contents	22.06 / 23.32	=	0.95

In both species ^{226}Ra concentration ratios from diet to bone are higher than those to other tissues; this probably reflects the radionuclide being incorporated in the bone matrix in the same way as its analogue Ca (Friedlander and Kennedy 1962; Lloyd et al. 1976; Raabe et al. 1983). Concentration in soft tissue (Mahon 1982; Schlenker et al. 1982; Swanson 1983; Ruttenber et al. 1984) does occur, but to a lesser extent than in bone. Bound in calcium hydroxyapatite bone crystals, ^{226}Ra may cause tissue damage, possibly resulting in osteosarcoma, as it is an internal emitter of alpha and beta radiation (Van Dilla et al. 1958; Mays et al. 1975; Schlenker et al. 1982; Raabe et al. 1983).

The concentration ratios reported here are lower than those (19.6 - 29.0) calculated from diet (cattails) to bones of muskrats taken at Elliot Lake in waters with historically high contamination levels (Mirka 1988). In moose, the reported CRs from vegetation (95 % confidence intervals) are: to bone, 1.30 - 7.04; to muscle, 0.027 - 0.048; and to liver, 0.054 - 0.091 (MacLaren 1987). The concentration ratios for beaver tissues calculated herein overlap those of the moose study with the exception that liver values are less than a quarter of the moose values. The grouse values fall within the moose range in the case of muscle, but are lower in bone and higher in liver. Expectation that the chyme of grouse would have a higher level of ^{226}Ra because of the bird's habit of picking up grit (possibly containing contaminants) for use as grinding stones in the gizzard, was not supported by the data. Nor was there any appreciable difference along the length of the gut related to absorption of the radionuclide. Muth and Glöbel (1983) calculated a concentration ratio of 23.7 between ^{226}Ra in food and human tissue.

estimates of annual intakes

Although consumption of beaver is probably not as common now as it was in the past, grouse are still considered a delicacy and are much sought after by residents of the Serpent River basin. Trappers and hunters of the area report beaver and grouse (along with muskrat, rabbit, and hare) are roasted or, in the cases of beaver and muskrat, stewed with onions and tomatos, before eating. Stewing exposes game to mild acidity, due to the presence of tomatos, which may elute some ^{226}Ra and Ca from the bones in the carcass. Levels of such liberation is unknown.

Estimates of annual consumption involve assumptions regarding quantities of tissue consumed per year. Goldfarb (1977) reported local hunters consume 46 kg of game per family per year. This consumption supplements or replaces dietary animal material from other sources. According to Health and Welfare Canada (HWC 1975) average annual consumption of all meats by Canadian males 20 to 29 y old is 71 kg. To make a very conservative assessment, it is assumed here that a resident of the Serpent River basin might obtain all his animal material from wild sources and that muscle tissue, liver tissue, and bone particles are consumed in the (arbitrary) ratio of 100:10:1. These assumptions lead to an estimated daily consumption of about 175 g of muscle, 17.5 g of liver, and 1.8 g of bone.

The above tissue consumption rates, used in conjunction with the tissue radionuclide values of Table 6, permitted estimation of annual intakes of radionuclides from each species. Detection limit values were used in those cases in which a radionuclide was not measurable in a tissue sample from one animal, but was measurable in the same tissue in the second representative examined. Values were converted to mBq.g^{-1} wet weight using the mean water contents of tissues measured during ^{226}Ra estimations (n = 10 in all cases): Beaver bone 36.6 %, muscle 72.5 %, liver 69.4 %, kidney 74.2 %; Grouse bone 41.5 %, muscle 72.6 %, liver 67.9 %, kidney 71.6 %. For levels of ^{226}Ra in bone, both the CANMET and MONENCO values were included in the calculations; CANMET values

were used for ^{226}Ra in muscle and liver.

Calculated annual intakes of radionuclides from beaver are as follows:

	bone	muscle	liver	total	% of derived limit on annual intake[2]
^{238}U (mg)	<1	4	<1	<6	<0.09
^{232}Th (mg)	nm	nm	nm	-	-
^{232}Th (Bq)	nm	nm	nm	-	-
^{230}Th (Bq)	nm	nm	nm	-	-
^{228}Th (Bq)	5	nm	nm	5	0.01
^{210}Po (Bq)	52	849	110	1,011	10.11
^{210}Pb (Bq)	63	nm	nm	63	1.58
^{226}Ra (Bq)	51	68	5	124	0.62

nm = not measurable in tissue of either specimen

and from grouse tissues:

	bone	muscle	liver	total	% of derived limit on annual intake[2]
^{238}U (mg)	<1	6	<1	<8	<0.12
^{232}Th (mg)	nm	nm	nm	-	-
^{232}Th (Bq)	nm	nm	nm	-	-
^{230}Th (Bq)	nm	nm	nm	-	-
^{228}Th (Bq)	nm	127	nm	127	0.25
^{210}Po (Bq)	9	117	353	479	4.79
^{210}Pb (Bq)	nm	nm	114	114	2.85
^{226}Ra (Bq)	19	75	7	101	0.51

nm = not measurable in tissue of either specimen

These estimated values are extremes assuming high consumption levels and no loss of radionuclides during cooking. Detection limit values, which probably overestimate concentrations, are used in some cases. Furthermore, data for each species came from only two specimens and these were selected because their tissue burdens of ^{226}Ra were high relative to others.

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2 **Explanatory note:**
These are extreme estimates based on 'worst-case' assumptions concerning consumption rates and use values from only two animals, from the most contaminated areas, which had been selected for their high levels of ^{226}Ra. It is considered unlikely that consumers would take in their diets even one tenth the amount of game used in these calculations. As a consequence, their aggregate annual intake would be 1.2% of the limit on annual intake in the case of beaver and 0.9% in the case of grouse. See text (p. 46) for more details.

To indicate the magnitude of radionuclide intakes the values are compared to one tenth of the values of Annual Limits on Intake for occupational workers given by the ICRP (1979a,b). These values, which may be considered as maximum yearly radionuclide intake, are as follows: ^{210}Pb - 4000 Bq, ^{210}Po - 10,000 Bq, ^{226}Ra - 20,000 Bq, ^{228}Th - 50,000 Bq, ^{230}Th - 40,000 Bq, ^{232}Th 7,000 Bq (1,550 mg), ^{238}U - 80,000 Bq (6,500 mg). These levels approximate the Canadian regulatory dose limits for the members of the public. Clearly, estimated values of annual radionuclide intakes from consumption of beaver or grouse are considerably less than the limits on yearly intake.

As indicated, these are extreme estimates based on 'worst-case' assumptions concerning consumption rates and use values from only two animals, from the most contaminated areas, which had been selected for their high levels of ^{226}Ra. It is considered unlikely that consumers would take in their diet even one tenth of the amount used in these calculations: trappers in the vicinity of Elliot Lake rarely, if ever, eat any of the beaver that they catch; grouse, although considered a delicacy and much sought after as a consequence, are difficult to obtain in numbers and are subject to legal season and catch (bag) limitations. Members of the Serpent River Band, located in the Low-Serpent area, probably consume more game, in relation to meat of domestic orgin, in their diet, compared to that in the diet of Elliot Lake residents. However, this wild meat is likely to be substantially lower in radionuclides than that consumed by Elliot Lake inhabitants (if radionuclides occur in the same proportion to ^{226}Ra); mean ^{226}Ra levels in bone and muscle of beaver from Low-Serpent are 20% and 30% respectively of values obtained at Elliot Lake. Beaver liver and grouse tissues contain ^{226}Ra levels not significantly higher than in samples taken from undisturbed control areas. Assuming the more realistic consumption level of 7.1 kg.y^{-1} then aggregate annual intake from wild game would be only 1.2% of the limit on annual intake in the case of beaver and 0.9% in the case of grouse.

quality assurance

Duplicate estimates were performed on six bone samples: two low-level beaver bones (from the Control-distant site) were analysed twice in the CANMET laboratory; two high-level beaver and two high-level grouse from the experimental areas were analysed at CANMET and also at the MONENCO laboratory. The latter analysis was performed blind. Results of the duplicate estimations are contained in Table 9:

Table 9. Levels of ^{226}Ra (mBq.g^{-1} dry weight) in beaver and grouse bone: repeated measures

	[Ra-226] mBq.g^{-1} dry weight of tissue	
sample	first measure	second measure
BO102 (beaver, Control-distant)	11.12^{c}	4.5^{c}
BO103 (beaver, Control-distant)	20.21^{c}	8.1^{c}
DSC 2 (beaver, Elliot Lake)	90.0 ± 10^{m}	119.6^{c}
DSC 8 (beaver, Elliot Lake)	120.0 ± 10^{m}	124.8^{c}
GEL 1 (grouse, Elliot Lake)	10.0 ± 5.0^{m}	142.5^{c}
GEL 5 (grouse, Elliot Lake)	<5.0^{m}	20.8^{c}

^{c} measured at CANMET laboratory, Elliot Lake.
^{m} measured at MONENCO laboratory, Calgary.

Samples of cow shank bone spiked with ^{226}Ra and ^{133}Ba, were run through the analytical procedure and showed recovery rates of 98 ± 10 %. Standard samples from CANMET, similarly processed, gave results within 10 % of the known values.

The agreement of the duplicate analyses in both low and high level samples is good in most cases and indicates that confidence may be put in the experimental results. The difference in levels measured in GEL 1 bone can not be accounted for.

CONCLUSIONS

a) The findings indicate that radionuclide contamination of beaver and grouse bone is localized. Only beaver taken in the immediate vicinity of U operations in the Elliot Lake area show high ^{226}Ra levels: those taken from waters with mean ^{226}Ra concentrations > 148 mBq.l^{-1} in the period 1984-1988, have bone ^{226}Ra levels higher than animals taken from local control areas. Grouse from Elliot Lake have bone radionuclide levels higher than distant controls, but similar to local controls. However, levels of ^{226}Ra in bone of beaver taken in Elliot Lake waters with lower mean ^{226}Ra concentrations (≤ 147 mBq.l^{-1}) even though trapped close to U operations, do not differ from those of specimens from local undisturbed control areas; those taken down-stream in the Serpent River do not differ from distant controls.

Level of ^{226}Ra in beaver muscle decline with site of capture and animals from the Low-Serpent area are not distinguishable from distant controls. Levels in kidney of beaver taken in the study area were all significantly higher than those of distant controls. Levels in beaver liver, and muscle, liver, and kidney tissue of grouse, showed no significant elevation associated with site.

b) Levels of ^{226}Ra in diet and tissues of beaver and grouse are similar to those reported in other studies of animals and plants in the study area.

c) Concentration ratios of ^{226}Ra between diets and beaver and grouse tissues are comparable to those reported for other animals in the area.

d) Levels of ^{226}Ra in fetal tissues are generally higher than in maternal tissues, and fetal liver has concentrations higher than other fetal tissues. Tissue levels of ^{226}Ra may be related to size (age) of the fetus in the case of beaver.

e) Radionuclides other than ^{226}Ra are present in beaver and grouse tissues

at low levels.

f) Radionuclide intakes by humans consuming even substantial amounts of beaver or grouse taken in the Serpent River drainage basin, are calculated to be less than current yearly limits established by regulatory authorities in Canada.

Lines of further inquiry:

a) A study of changes in ^{226}Ra levels during fetal development of laboratory animals in mothers fed a diet spiked with ^{226}Ra, could extend observations made on fetal levels in this current report.

c) As fetal tissues in general, and liver in particular, have higher radionuclide levels than those found in maternal tissues, an investigation of radionuclide burdens in tissues of young humans could be a rewarding study. A first step in this direction would be be to study fetal and placental (afterbirth) material, and deciduous teeth of children, obtained from the Elliot Lake and Serpent River regions.

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APPENDIX I. Beaver specimens processed in study

sex	#	taken (m/d/y)	place	coordinates (° ' "N)(° ' "W)	age est. (y)	body wt. (skinned) (g)	[^{226}Ra] (- - - mBq.g^{-1} d.w. - - -) bone	musc.	liv.	kid.	stom.
1986											
ELLIOT LAKE											
m	BF1	10/20/86	nr Nordic & Lacnor tlgs	46 23 00 82 37 30	1.5-2.0	11,545	48.8				
m	BF7	10/26/86	nr Nordic & Lacnor tlgs	46 23 00 82 37 30	1.5-2.0	12,120	52.5				
m	BF9	10/20/86	Home L	46 23 30 82 39 00	≥4.5	19,340	109.0				
m	BF10	fall 86	nr Nordic & Lacnor tlgs	46 23 00 82 37 30	1.5-2.0	12,075	114.3				
m	BF12	10/22/86	nr Nordic & Lacnor tlgs	46 23 00 82 37 30	1.5-2.0	8,725	57.2				
m	BF14	10/22/86	1km N Westner L	46 23 30 82 37 00	2.5-3.0	11,313	82.6				
m	BF16	fall 86	500m N of NE tip Elliot L	46 24 30 82 40 00	1.5-2.0	10,270	38.1				
m	BF21	10/28/86	NW Crotch L	46 26 40 82 36 50	≥4.5	15,550	38.0				
m	BF22	fall 86	NW of Crotch L	46 26 20 82 36 00	≥4.5	15,090	52.2				
m	BF24	10/26/86	SW of SW tip Quirke L	46 26 40 82 35 00	2.5-3.0	10,155	21.5				
m	BF27	fall 86	Stream N of Crotch L	46 26 20 82 36 00	3.5-4.0	15,490	35.6				
m	BF29	10/28/86	NW of Crotch L	46 26 40 82 36 50	0.5-1.0	6,800	43.2				
m	BF30	10/28/86	NW of Crotch L	46 26 40 82 36 50	≥4.5	19,335	18.9				
m	BF31	10/28/86	2km E of 108, level S tip Quirke L	46 27 00 82 38 00	≥4.5	15,372	17.7				
m	BF40	10/28/86	adj 108, level S tip Quirke L	46 27 00 82 38 30	1.5-2.0	9,515	164.0				
m	BF42	10/31/86	adj 108, level S tip Quirke L	46 27 30 82 39 30	1.5-2.0	14,470	15.9				
m	BF44	10/31/86	adj 108 2km N Elliot L	46 25 00 82 40 00	≥4.5	13,173	15.9				
m	BF47	10/31/86	equid Nordic and Ryan LL	46 22 20 82 34 50		19,560	39.8				
m	BF49	10/31/86	Bawden LL, S of SE extent Elliot L	46 21 50 82 40 30	3.5-4.0	12,250	21.7				
m	BF50	10/31/86	Bawden LL, S of SE extent Elliot L	46 22 00 82 41 00	0.5-1.0	5,300	28.8				
m	BF58	11/1/86	twixt 108 and Strouth L	46 25 20 82 39 20	1.5-2.0	9,340	51.0				
m	BF59	11/1/86	twixt 108 and Strouth L	46 25 20 82 39 20		8,300	52.2				
m	BF61	11/1/86	Crotch L (S)	46 25 30 82 36 00	≥4.5	17,722	97.3				
m	BF64	10/31/86	c 2km W 108,1 km N Elliot L	46 24 50 82 42 00	≥4.5	12,485	10.5				
m	BF65	11/1/86	c 2km W 108,1 km N Elliot L	46 25 30 82 41 40	0.5-1.0	5,425	30.1				
m	BF71	11/1/86	c 2km S Home L	46 22 20 82 38 30	0.5-1.0	2,682	17.3				
m	BF80	11/10/86	c 1km NW of Stinson L	46 23 40 82 33 00	2.5-3.0	15,120	245.7				
m	BF81	11/9/86	c 1km NW of Stinson L	46 23 30 82 32 50	1.5-2.0	12,820	35.9				
m	BF84	11/10/86	Stream 0.5 km W Stinson L	46 23 10 82 32 50	3.5-4.0	12,579	29.2				
m	BF85	11/10/86	Stream 0.5 km W Stinson L	46 23 10 82 32 50	1.5-2.0	10,284	134.0				
m	BF86	11/10/86	Stream 0.5 km W Stinson L	46 23 10 82 32 50	1.5-2.0	8,714	145.0				
m	BF87	11/10/86	Nordic L (NE)	46 21 50 82 35 00	≥4.5	17,685	108.6				
m	BF90	11/10/86	Nordic L (E)	46 21 50 82 36 00		14,432	96.1				
m	BF91	11/10/86	Nordic L (SW)	46 21 30 82 36 30	≥4.5	16,128	128.6				
m	BF92	fall 86	Nordic L (SW)	46 21 30 82 36 30	≥4.5	18,132	158.7				
m	BF93	11/10/86	Nordic L (NW)	46 22 00 82 36 40	0.5-1.0	7,204	94.7				
m	BF97	11/10/86	Str equidi N Nordic and Stinson L	46 23 20 82 33 40	2.5-3.0	9,453	65.9				
m	DS1	fall 86	Str below Dam R (MOE), Panel tlgs	46 30 40 82 32 00	≥4.5	16,215	41.8				
m	DS5	fall 86	adj 108, circa 1km S Flag L	46 27 30 82 39 00	2.5-3.0	12,474	45.5				
m	DS6	fall 86	W extremity Rochester L	46 31 40 82 31 30	0.5-1.0	4,585	77.6				
m	DS7	fall 86	W Strike L (Panel tlgs)	46 31 30 82 32 40	1.5-2.0	9,740	31.2				
m	DS9	fall 86	Mid-N part Rochester L	46 31 30 82 30 30		4,641	32.5				
m	DS12	fall 86	c 2 km NE of NE corner Quirke L	46 32 00 82 30 00	0.5-1.0	5,112	44.5				
m	DS17	fall 86	Uranium L	46 31 00 82 29 00	1.5-2.0	9,208	39.6				
m	DS19	fall 86	c 1 km NE of NE corner Quirke L	46 32 00 82 30 00	0.5-1.0	5,338	63.2				
m	DS21	fall 86	W extremity Rochester L	46 31 40 82 31 30	0.5-1.0	4,820	55.5				
m	DS24	fall 86	W extremity Rochester L	46 31 40 82 31 30	0.5-1.0	4,571	77.4				
m	DS34	fall 86	500m N of Poppy L	46 27 00 82 32 30	0.5-1.0	5,467	64.3				
m	DS35	fall 86	Mellon L	46 27 50 82 36 50	1.5-2.0	9,626	9.4				
m	DS36	fall 86	Gander L	46 28 00 82 36 50	0.5-1.0	4,910	78.0				
m	DS42	fall 86	Poppy L	46 26 50 82 32 20	0.5-1.0	3,820	62.0				
m	DS44	fall 86	500m NE Poppy L	46 27 10 82 31 30	1.5-2.0	10,690	103.1				
m	DS45	fall 86	500m N Poppy L	46 27 00 82 32 30	0.5-1.0	5,103	67.0				
m	DS48	fall 86	NW Quirke L	46 30 50 82 35 20	0.5-1.0	5,525	104.7				
f	BF2	10/?/86	nr Nordic & Lacnor tlgs	46 23 00 82 37 30	0.5-1.0	7,200	56.8				
f	BF5	10/26/86	Home L	46 23 30 82 39 00	0.5-1.0	5,397	55.6				
f	BF6	10/22/86	Home L	46 23 30 82 39 00	≥4.5	15,805	50.5				
f	BF8	10/26/86	nr Nordic & Lacnor tlgs	46 23 00 82 37 30	1.5-2.0	11,435	57.7				
f	BF11	10/?/86	nr Nordic & Lacnor tlgs	46 23 00 82 37 30	0.5-1.0	6,927	66.3				
f	BF17	10/24/86	1km SW Sheriff L	46 24 00 82 37 00	0.5-1.0	3,900	147.0				
f	BF19	10/26/86	North Nordic L	46 23 00 82 35 00	1.5-2.0	8,560	149.8				
f	BF20	10/28/86	North Nordic L	46 23 00 82 35 00	0.5-1.0	4,975	89.9				
f	BF23	10/?/86	Stream dr into N Crotch L	46 26 20 82 36 00	3.5-4.0	12,770	44.7				
f	BF25	10/26/86	Stream dr into N Crotch L	46 26 20 82 36 00	3.5-4.0	12,767	55.3				
f	BF26A	10/26/86	Stream dr into N Crotch L	46 26 20 82 36 00	≥4.5	13,710	186.8				
f	BF32	10/28/86	2km E 108 level S tip Quirke L	46 27 00 82 38 00	1.5-2.0	9,050	22.5				
f	BF33	10/28/86	Stream dr into N of Crotch L	46 26 20 82 36 00	3.5-4.0	14,360	32.7				
f	BF34	10/28/86	Stream dr into N of Crotch L	46 26 20 82 36 00	0.5-1.0	5,963	19.3				
f	BF35	10/28/86	Mellon L, W of S tip of Quirke L	46 26 50 82 35 30	≥4.5	24,365	33.0				

APPENDIX I...continued

sex	#	taken (m/d/y)	place	coordinates (° ' "N)(° ' "W)	age est. (y)	body wt. (skinned) (g)	[^{226}Ra] (- - - mBq.g^{-1} d.w. - - -) bone	musc.	liv.	kid.	stom.
f	BF36	10/7/86	adj 108, level S tip of Quirke L	46 28 00 82 39 30	1.5-2.0	12,335	23.1				
f	BF37	10/28/86	adj 108, level S tip of Quirke L	46 28 00 82 39 30	2.5-3.0	12,600	40.3				
f	BF39	10/28/86	adj 108, level S tip of Quirke L	46 27 00 82 38 30	1.5-1.0	4,658	23.0				
f	BF43	10/31/86	adj 108, level S tip of Quirke L	46 27 30 82 39 30	2.5-3.0	14,220	18.3				
f	BF45	10/31/86	adj 108, 2km N Elliot L	46 25 00 82 40 00	1.5-2.0	8,765	28.4				
f	BF46	10/31/86	adj 108, 2km N Elliot L	46 25 00 82 40 00	≥4.5	13,065	28.9				
f	BF48	10/31/86	Bawden LL, S of SE extrem Elliot L	46 21 50 82 40 30	1.5-2.0	13,250	111.1				
f	BF51	10/31/86	Bawden LL, S of SE extrem Elliot L	46 21 50 82 40 50	≥4.5	19,810	11.8				
f	BF52	10/31/86	Bawden LL, S of SE extrem Elliot L	46 21 50 82 41 50	≥4.5	16,552	19.4				
f	BF55	10/31/86	0.5 km S of SE extrem Elliot L	46 22 50 82 42 30	1.5-2.0	12,045	21.2				
f	BF56	10/31/86	0.5 km S of SE extrem Elliot L	46 22 50 82 42 30		19,575	10.1				
f	BF60	11/1/86	twixt Sheriff and Penelope LL	46 24 40 82 37 30	≥4.5	15,878	122.6				
f	BF63	11/1/86	c 2km W 108 and 1 km N Elliot L	46 24 50 82 42 00	≥4.5	15,830	64.2				
f	BF66	11/5/86	c 2km W 108 and 1 km N Elliot L	46 25 50 82 42 00	0.5-1.0	6,630	22.0				
f	BF67	11/5/86	c 2km W 108 and 1 km N Elliot L	46 25 50 82 42 00	2.5-3.0	12,875	13.2				
f	BF68	11/5/86	c 2km W 108 and 1 km N Elliot L	46 25 30 82 42 00	≥4.5	18,855	19.2				
f	BF69	11/5/86	S.E. corner Crotch L	46 25 10 82 35 20		6,085	62.9				
f	BF73	11/7/86	Porridge L	46 22 40 82 37 20	1.5-2.0	13,960	65.7				
f	BF74	11/8/86	Porridge L	46 22 40 82 37 20	0.5-1.0	5,728	45.8				
f	BF76	11/8/86	Str equid Nordic and Ryan L	46 22 30 82 35 20	≥4.5	18,040	892.2				
f	BF77	11/10/86	Str equid Nordic and Ryan L	46 22 30 82 35 20	1.5-2.0	11,891	701.4				
f	BF78	11/8/86	Str equid Nordic and Ryan L	46 22 30 82 35 20	0.5-1.0	6,343	844.3				
f	BF79	11/10/86	c 1km NW Stinson L	46 23 40 82 33 00	1.5-2.0	11,107	439.2				
f	BF82	11/7/86	Stinson L	46 23 20 82 32 40	2.5-3.0	13,793	96.9				
f	BF83	11/10/86	Stinson L	46 23 20 82 32 40	≥4.5	17,039	81.9				
f	BF88	11/10/86	Nordic L (NE)	46 21 50 82 35 00	≥4.5	16,685	170.3				
f	BF89	11/10/86	Nordic L (SW)	46 21 30 82 36 30	1.5-2.0	11,985	122.6				
f	BF94	11/7/86	Nordic L (NW)	46 22 00 82 36 40	≥4.5	18,790	48.5				
f	BF95	10/11/86	Nordic L (NW)	46 22 00 82 36 40	1.5-2.0	9,494	274.7				
f	BF96	11/7/86	Str equid N. Nordic and Stinson L	46 23 20 82 33 40	1.5-2.0	80	183.7				
f	BF98	11/10/86	Str equid N. Nordic and Stinson L	46 23 20 82 33 40	3.5-4.0	10,911	26.9				
f	BF99	fall 86	Str equid N. Nordic and Stinson L	46 23 20 82 33 40	0.5-1.0	5,752	354.3				
f	BF100	11/10/86	Str equid N. Nordic and Stinson L	46 23 20 82 33 40		10,115	312.2				
f	DS11	fall 86	c 3 km NE of NE corner Quirke L	46 31 00 82 36 00	0.5-1.0	4,747	44.4				
f	DS13	fall 86	Uranium L	46 31 00 82 29 00	1.5-2.0	10,360	67.1				
f	DS16	fall 86	W extrem Rochester L	46 31 40 82 31 30	0.5-1.0	4,627	100.3				
f	DS22	fall 86	Poppy L	46 26 50 82 32 20	0.5-1.0	4,793	61.5				
f	DS23	fall 86	W of North Span L	46 28 20 82 35 00	2.5-3.0	11,804	133.9				
f	DS31	fall 86	Panel tlgs drainage	46 31 00 82 31 00	0.5-1.0	5,534	68.4				
f	DS33	fall 86	S of Rochester L, just E of Panel tlgs	46 31 20 82 30 30	< 0.5	2,707	30.5				
f	DS43	fall 86	Poppy L	46 26 50 82 32 20	1.5-2.0	9,199	59.7				
f	DS46	fall 86	Stollery L	46 29 00 82 38 30	0.5-1.0	5,802	51.1				
f	RL 101	8/29/86	Panel tlgs below MOE dam 'A'	46 31 00 82 31 30	1.5-2.0	10,127	35.5				
f	RL 104	9/14/86	Johnson Ck	46 30 50 82 37 50	1.5-2.0		193.4				
m	RL 102	fall 86	Panel tlgs below MOE dam 'A'	46 31 00 82 31 30	≥4.5		212.0				
m	RL 103	fall 86	Panel tlgs below MOE dam 'A'	46 31 00 82 31 30	2.5-3.0	13,239	141.6				
m	RL 105	9/23/86	Johnson Ck, 100m E of tlg discharge	46 30 50 82 37 50	1.5-2.0		29.6				
m	EB1-101	fall 85	Quirke L	46 30 00 82 34 00	0.5-1.0	3,863	176.8				
m	EB1-102	fall 85	Quirke L	46 30 00 82 34 00	1.5-2.0	10,824	228.0				
?	EB1-103	fall 85	Sheriff Ck	46 24 30 82 37 20	2.5-3.0		236.1				
f	EB1-104	8/18/85	Sheriff Ck.	46 24 30 82 37 20		21,020	176.8				
CONTROL - LOCAL											
m	RB1	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	3.5-4.0	13,107					
m	RB3	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	13,660					
m	RB4	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	0.5-1.0	5,885	58.5				
m	RB6	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	0.5-1.0	5,135	27.7				
m	RB7	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	2.5-3.0	14,903					
m	RB8	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	≥4.5	16,698					
m	RB12	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	8,803					
m	RB14	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	≥4.5	15,852					
m	RB15	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	11,840					
?	RB16	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	0.5-1.0	6,507					
f	RB2	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	11,410					
f	RB5	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	7,060	54.8				
f	RB9	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	10,674	64.8				
f	RB10	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	10,560					
f	RB11	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	10,975	60.1				
f	RB13	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	9,430					
m	RB102	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	0.5-1.0	6,350	28.9				
m	RB104	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	3.5-4.0	15,938	49.6				
f	RB101	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	10,490	69.1				
f	RB103	fall 86	Tweedle Twp., 35km N Elliot L	±46 45 00±82 45 00	1.5-2.0	11,350	63.5				

APPENDIX I...continued

sex	#	taken (m/d/y)	place	coordinates (° ' "N)(° ' "W)	age est. (y)	body wt. (skinned) (g)	[^{226}Ra] (- - - mBq.g^{-1} d.w. - - -) bone	musc.	liv.	kid.	stom.
CONTROL - DISTANT											
m	BO104	11/8/86	Rathbun Twp	±46 45 00±80 38 00		11,000	40.1				
m	BO106	11/8/86	Rathbun Twp	±46 45 00±80 38 00		18,000	20.7				
m	BO107	11/8/86	Rathbun Twp	±46 45 00±80 38 00		10,034	13.8				
m	BO108	11/8/86	Rathbun Twp	±46 45 00±80 38 00		4,086	20.0				
m	BO109	11/8/86	Rathbun Twp	±46 45 00±80 38 00		17,699	21.6				
m	BO110	11/8/86	Stull Twp	±47 17 00±81 00 00		12,417	17.7				
f	BO101	fall 86	McLeod Twp	±47 17 00±80 52 00	0.5-1.0	5,214	20.2				
f	BO102	fall 86	Stull Twp	±47 17 00±81 00 00	0.5-1.0	7,130	4.5	1.9	1.1	0.6	
f	BO103	11/7/86	Rathbun Twp	±46 45 00±80 38 00	3.5-4.0	9,764	8.1	1.1	0.4	2.1	
f	BO105	11/8/86	Rathbun Twp	±46 45 00±80 38 00		13,449	21.3				
m	cb2-102	2/22/86	Rathbun Twp	±46 45 00±80 38 00	0.5-1.0	7,642	15.5	0.3	2.0	1.9	
m	cb2-103	2/22/86	Rathbun Twp	±46 45 00±80 38 00	0.5-1.0	5,467	30.5	0.9	2.3	3.0	
m	cb2-106	2/22/86	Rathbun Twp	±46 45 00±80 38 00	0.5-1.0	7,507	19.2	1.1	0.9	2.9	
f	cb2-101	spring 86	Rathbun Twp	±46 45 00±80 38 00	1.5-2.0	7,368	24.8	1.0	1.8	4.9	
f	cb2-104	2/22/86	Rathbun Twp	±46 45 00±80 38 00	0.5-1.0	7,675	19.9	0.8	5.1	0.8	
f	cb2-105	2/22/86	Rathbun Twp	±46 45 00±80 38 00	0.5-1.0	6,038	29.4	0.2	2.2	1.4	
f	cb2-107	2/22/86	Rathbun Twp	±46 45 00±80 38 00	0.5-1.0	4,950	22.3	1.1	1.7	4.3	
f	cb2-108	2/22/86	Rathbun Twp	±46 45 00±80 38 00	0.5-1.0	6,112	22.7	2.0	0.8	2.7	
1987											
ELLIOT LAKE											
m	DS(C) 1	4/5-10/87	Serpent r - 3km E of Algom-Qui Bldgs	46 30 50 82 36 00	0.5-1.0	6,118	104.7	10.2	2.3	13.0	29.7
m	DS(C) 2	4/5-10/87	Serpent r - 3km E of Algom-Qui Bldgs	46 30 50 82 36 00	0.5-1.0	6,630	123.0	2.1	2.6	2.5	3.0
m	DS(C) 3	4/5-10/87	Serpent r - 4km E of Algom-Qui Bldgs	46 30 40 82 35 30	1.5-2.0	5,786	91.9	4.2	1.4	11.0	2.9
m	DS(C) 4	4/5-10/87	Serpent r - 3km E of Algom-Qui Bldgs	46 30 50 82 36 00	1.5-2.0	5,640	111.0	4.5	5.4	12.7	6.2
m	DS(C) 5	4/5-10/87	Serpent r - 4km E of Algom-Qui Bldgs	46 30 50 82 35 30	1.5-2.0	13,075	88.8	2.0	1.1	8.4	60.7
m	DS(C) 6	4/5-10/87	Serpent r - 3km E of Algom-Qui Bldgs	46 30 50 82 36 00	1.5-2.0	5,795	113.7	0.6	1.3	5.8	30.0
m	DS(C) 8	4/5-10/87	3.5km S Algom-Qui Bldgs, 400m E rd	46 29 50 82 37 50	3.5-4.0	15,597	124.8	4.9	2.8	27.5	263.7
m	DS(C) 10	4/5-10/87	3.5km S Algom-Qui Bldgs, 400m E rd	46 29 50 82 37 50	3.5-4.0	15,178	111.1	2.6	2.4	10.8	67.7
f	DS(C) 7	4/5-10/87	Serpent r - 4km E of Algom-Qui Bldgs	46 30 40 82 35 30	0.5-1.0	6,010	94.2	2.6	2.9	8.0	120.3
f	DS(C) 9	4/5-10/87	3.5km S Algom-Qui Bldgs, 400m E rd	46 29 50 82 37 50	1.5-2.0	8,685	116.2	2.7	4.6	8.0	194.8
MID-SERPENT											
m	WL(C)7	3/22/87	NW Kindle (Bear) L, nr Nook L entry	46 28 30 82 25 00	0.5-1.0	5,127	68.3	1.4	0.9	4.6	13.8
f	WL(C)1	4/30/87	twixt Whiskey and Pecors LL	46 23 00 82 25 00	1.5-2.0	8,120	174.2	4.0	4.7	16.7	32.8
f	WL(C) 4	3/22/87	Sandy pt, Whiskey L nr Kindle L entry	46 28 00 82 22 30	≥4.5	19,245	28.4	3.6	3.9	4.6	15.2
f	WL(C)9	3/22/87	Pine pt, N Whiskey L	46 27 00 82 20 20	0.5-1.0	5,883	59.0	5.9	5.0	10.0	56.0
m	1000	12/17/87	Pecors L	46 15 00 82 27 30	1.5-2.0	7990	5.7	0.3	1.5	1.6	3.1
m	2000	12/17/87	Pecors L	46 15 00 82 27 30	0.5-1.0	5300	7.9	4.5	3.7	3.7	4.4
m	3000	2/25/88	NW corner Kindle L near Nook L entry	46 28 30 82 25 00		10,857	41.8	1.2	2.5	5.2	17.7
m	4000	2/25/88	Whiskey L, NE corner Campbell Isle	46 27 00 82 19 00		11,024	28.5	4.6	7.2	3.5	22.4
f	5000	2/25/88	NW corner Kindle L near Nook L entry	46 28 30 82 25 00		19,580	46.8	1.8	5.1	2.	10.1
m	6000	2/25/88	Whiskey L, NE corner Campbell Isle	46 27 00 82 19 00		8,278	31.3	1.5	2.4	3.1	19.3
m	7000	2/22/88	Whiskey L, SW Isle off Shelter pt	46 24 30 82 20 30		16,249	7.9	2.5	1.0	4.1	2.9
LOW-SERPENT											
m	SR(C)1	3/31/87	Atomic drive-in Movie, nr S.R. village	46 12 00 82 37 00	1.5-2.0	10,770	61.3	1.3	9.9	20.6	42.6
m	SR(C)3	3/31/87	Serpent r, 1km w of drive-in	46 12 00 82 37 00	≥4.5	16,012	23.1	2.0	4.1	5.4	8.5
m	SR(C)4	3/31/87	Serpent r, 1km w of drive-in	46 12 00 82 37 00	1.5-2.0	12,350	19.4	2.7	1.1	3.6	6.5
m	SR(C)5	3/31/87	Serpent r, 1km w of drive-in	46 12 00 82 37 00	3.5-4.0	15,580	67.4	1.6	3.5	7.2	18.0
m	SR(C)6	3/31/87	Serpent r, 1km w of drive-in	46 12 00 82 37 00	3.5-4.0	14,846	62.0	0.2	1.3	7.2	31.2
m	SR(C)10	3/31/87	Serpent r, 1km w of drive-in	46 12 00 82 37 00	≥4.5	18,072	38.2	2.8	0.7	2.6	2.8
f	SR(C)2	3/31/87	Serpent r, 1km w of drive-in	46 12 00 82 37 00	≥4.5	31,100	22.0	1.0	2.0	2.3	11.1
f	SR(C)7	3/31/87	Serpent r, 1km w of drive-in	46 12 00 82 37 00	1.5-2.0	13,637	41.6	1.6	1.6	2.7	26.6
f	SR(C)8	3/31/87	Serpent r, 1km w of drive-in	46 12 00 82 37 00	3.5-4.0	13,650	30.8	1.6	1.9	5.4	11.1
f	SR(C)9	3/31/87	Serpent r, 1km w of drive-in	46 12 00 82 37 00	2.5-3.0	12,258	8.0	1.0	2.5	3.0	42.8
f	SR(C)11	3/31/87	Serpent r, 1km w of drive-in	46 12 00 82 37 00	0.5-1.0	6,745	16.3	0.7	0.7	4.1	3.7
f	SR(C)12	3/31/87	Lizard L (nr 'Forks')	46 14 00 82 30 00	1.5-2.0	7,807	41.4	1.5	1.3	4.0	3.8
f	SR(C)13	3/31/87	Lizard L (nr 'Forks')	46 14 00 82 30 00	1.5-2.0	12,398	11.1	1.5	2.9		10.9
f	SR(C)14	3/31/87	Grassy L	46 12 30 82 30 00	2.5-3.0	18,218	7.1	0.1	2.7	2.5	5.6
f	SR(C)15	3/31/87	Grassy L	46 12 30 82 30 00	3.5-4.0	16,600	11.3	2.1	0.9	1.2	0.8

APPENDIX II. Grouse specimens processed in study

sex	#	taken (m/d/y)	place	coordinates (° ' "N)	(° ' "W)	age est. (Ad/Im)	body wt. (g)	[^{226}Ra] (- - - - mBq.g^{-1} d.w. - - - -) bone	musc.	liv.	kid.	crop	stom.	int.
ELLIOT LAKE														
m	G-EL 1	11/16/87	circa Algoma-Quirke mine	46 31 00	86 38 00	I	588	150.2	1.7	16.1	31.7	154.7	22.2	43.5
m	G-EL 2	11/16/87	S shore Poppy L	46 26 45	82 33 30	A	643	12.0	0.9	12.5	10.5	72.4	22.1	16.3
m	G-EL 3	11/16/87	circa 2 km N of Algoma-Quirke mine	46 31 30	82 39 00	A	651	17.7	2.0	4.1	21.9	24.3	26.9	62.2
m	G-EL 4	11/16/87	circa 2 km N of Algoma-Quirke mine	46 31 30	82 39 00	A	703	18.2	4.2	4.7	15.3	5.0	12.8	20.1
m	G-EL 5	11/16/87	circa 4 km N of Algoma-Quirke mine	46 31 40	82 39 00	A	612	20.8	6.0	3.9	12.1	8.0	8.0	6.3
f	G-EL 6	11/16/87	NE tip Little Quirke L	46 32 30	82 33 30	A	528	16.4	2.3	9.3	34.4	21.1	11.8	18.0
m	G-EL 7	11/16/87	W tip Rochester L	46 31 30	82 31 30	A	689	14.4	4.6	5.5	55.1	16.4	9.2	50.9
m	G-EL 8	11/16/87	circa 2 km N of Algoma-Quirke mine	46 31 30	82 39 00									
m	G-EL9(200)	11/16/87	N of North Nordic L	46 23 00	82 35 30									
MID-SERPENT														
m	G-MS 1	11/16/87	1km N Pecors Lk on S.R.	46 25 30	82 27 30	A	567	9.6	4.2	4.1	24.4			
m	G-MS 2	fall 87	200m E of Whiskey L	46 27 00	82 19 00	A	part	15.1	6.5	10.1	23.1			
m	G-MS 3	fall 87	1km E of Whiskey L	46 27 00	82 18 50	A	part	16.2	7.3	8.6	50.0			
f	G-MS 4	fall 87	6km E of Whiskey L	46 27 00	82 17 30	I	part	12.6	1.9	9.2	22.5			
f	G-MS 5	fall 87	12km E of Whiskey L	46 27 00	82 15 30	I	part	30.3	15.1	11.0	15.4			
f	G-MS 6	fall 87	1km E of Whiskey L	46 27 00	82 18 50	A	part	28.8	20.6	18.0	26.5			
m	G-MS 7	fall 87	1km E of Whiskey L	46 27 00	82 18 50	A	part	20.9	9.6	2.6	21.1			
LOW-SERPENT														
m	G-LS 1	11/16/87	Grassy Lk(?)	46 13 00	82 30 00	A	620	5.1	3.3	17.2	8.5			
m	100	12/17/87	Serp R nr hwy 108 turnof	46 13 00	82 32 00	I	662							
?	100a	2/28/88	Hwy 17/Imp Oil Rd	46 13 00	82 32 00	?	381							
m	G-LS 4	3/28/88	Grassy L	46 13 00	82 30 00	A	674	38.4	17.2	15.5	28.7			
m	G-LS 5	3/28/88	Grassy L	46 13 00	82 30 00	A	633	30.4	3.4	1.3	63.1			
m	G-LS 6	3/28/88	Grassy L	46 13 00	82 30 00	A	604	30.8		7.2	19.8			
?	G-LS 7	3/28/88	Grassy L	46 13 00	82 30 00	?	part	16.5	3.2					
?	G-LS 8	3/28/88	Grassy L	46 13 00	82 30 00	?	part	10.4	1.8					
?	G-LS 9	3/28/88	Grassy L	46 13 00	82 30 00	?	part	7.8	1.2					
CONTROL - LOCAL														
m	G-COL 1	fall 87	40km NW Elliot L	46 42 50	82 49 00	I	part	19.9	1.0	8.9	17.4			
m	G-COL 2	fall 87	40km NW Elliot L	46 42 50	82 49 00	A	part	45.4	6.0	10.7	29.0			
m	G-COL 3	fall 87	40km NW Elliot L	46 42 50	82 49 00	I	part	16.3	2.1	3.9	16.7			
f	G-COL 4	fall 87	40km NW Elliot L	46 42 50	82 49 00	I	part	56.7	9.2	1.2	13.0			
m	G-COL 5	fall 87	40km NW Elliot L	46 42 50	82 49 00	I	part	22.1	2.9	0.0	15.4			
f	G-COL 6	fall 87	40km NW Elliot L	46 42 50	82 49 00	I	part	24.6	20.1	7.8	14.7			
m	G-COL 7	fall 87	40km NW Elliot L	46 42 50	82 49 00	I	part	71.8	5.0	9.1	9.0			
m	G-COL 8	fall 87	40km NW Elliot L	46 42 50	82 49 00	I	part	31.5	3.4	5.3	17.4			
m	G-COL 9	fall 87	40km NW Elliot L	46 42 50	82 49 00	A	part							
f	G-COL 10	fall 87	40km NW Elliot L	46 42 50	82 49 00	I	part							
CONTROL-DISTANT														
m	G-COD 1	10/20/87	Wanapitei	46 45 00	80 39 00	I	547	9.6	5.2	7.2	47.9			
f	G-COD 2	10/20/87	Wanapitei	46 45 00	80 39 00	I	592	18.7	4.3	4.7	128.5			
m	G-COD 3	10/20/87	Wanapitei	46 45 00	80 39 00	I	570	49.7	5.7	3.7	179.9			
f	G-COD 4	10/20/87	Wanapitei	46 45 00	80 39 00	I	482	17.2	33.2	6.5	8.6			
f	G-COD 5	10/20/87	Wanapitei	46 45 00	80 39 00	I	492	8.1	4.5	26.7	18.7			
m	G-COD 6	10/20/87	Wanapitei	46 45 00	80 39 00	A	518	1.1	4.7	35.5	12.9			
m	G-COD 7	10/20/87	Wanapitei	46 45 00	80 39 00	I	521	5.5	4.2	2.3	22.2			
m	G-COD 8	10/20/87	Wanapitei	46 45 00	80 39 00	I	498	18.4	3.5	7.0	8.7			
f	G-COD 9	10/20/87	Wanapitei	46 45 00	80 39 00	A	590	20.2	8.5	5.9	17.4			
m	G-COD 10	10/20/87	Wanapitei	46 45 00	80 39 00	A	603	7.7	18.4	27.5	13.9			
m	G-COD 11	10/20/87	Wanapitei	46 45 00	80 39 00	A	549	6.4	6.1	18.5	4.2			
m	G-COD 12	10/20/87	Wanapitei	46 45 00	80 39 00	A	564	4.2	2.5	4.6	8.4			

APPENDIX III. Beaver and muskrat fetuses processed in study

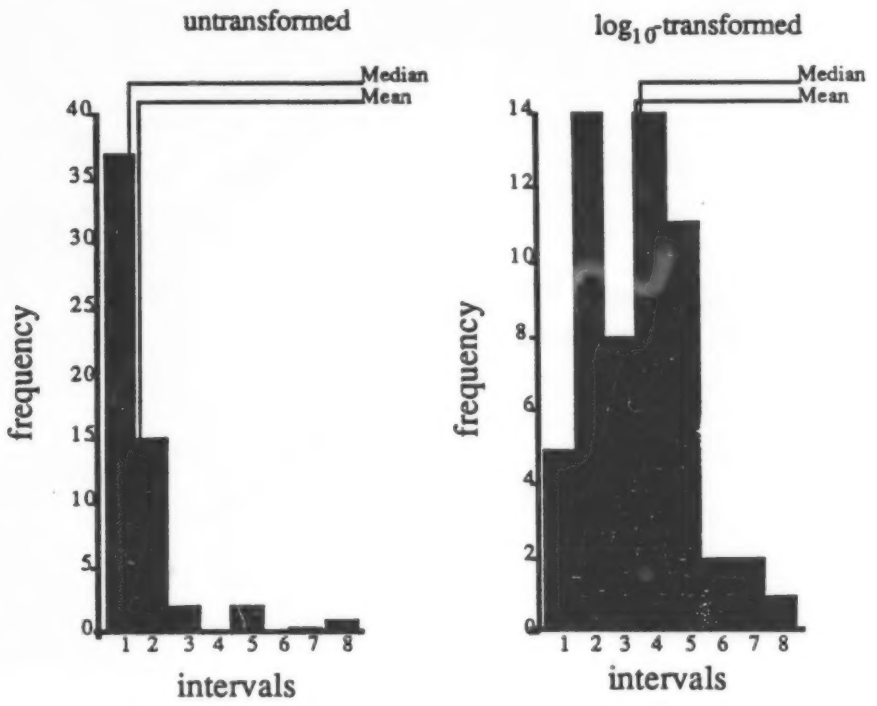
mother	foetus #	weight (fresh) g	C-R mm	liver tissue wt. (dry) mg	^{226}Ra $mBq.g^{-1}$ (dry wt.)	'residual' tissue wt. (dry) mg	^{226}Ra $mBq.g^{-1}$ (dry wt.)
beaver							
WLC 4	1	5	37	0.044	267.9	0.306	33.7
	2	4	39	0.027	123.9	0.293	43.7
	3	7	46	0.073	66.6	0.316	34.7
	4	6	46	0.081	135.0	0.237	48.3
SRB 15	1	15	-	0.084	97.5	0.335	4.6
	2	14	70	0.123	127.1	0.509	20.4
	3	14	61	0.084	163.2	0.431	84.7
	4	13	66	0.069	45.7	0.606	46.5
SRB 14	1	13	69	0.163	79.8	0.650	14.2
	2	20	71	0.096	56.8	0.892	19.9
	3	25	71	0.112	45.4	1.090	28.4
	4	29	69	0.151	144.6	0.885	15.1
	5	23	70	0.098	82.4	0.795	32.3
	6	24	71	0.081	67.6	0.683	51.1
SRB 2	1	70	99	0.522	19.4	1.902	5.5
	2	59	94	0.553	9.4	2.446	4.6
	3	65	95	0.374	41.7	3.186	3.6
muskrat							
EM 104	1	22	56	0.075	166.4	1.572	17.7
	2	23	67	0.070	0.0	1.291	28.3
	3	23	66	0.080	211.9	1.499	21.9
	4	22	66	0.159	73.3	1.525	17.3
	5	24	69	lost in processing		1.550	23.7
	6	24	67	0.097	89.5	1.818	22.2
EM 105	1	24	64	0.097	109.7	1.671	9.8
	2	24	64	0.020	564.5	1.575	4.7
	3	26	62	0.131	41.7	1.987	13.4
	4	24	69	0.076	99.4	1.561	11.8
	5	24	66	0.105	87.4	1.533	15.3
	6	24	60	0.135	41.5	1.483	9.6
	7	23	-	0.099	108.4	1.817	6.7
	8	23	64	0.109	45.2	1.294	8.5

APPENDIX IV. Water quality at locations in the Serpent River Basin (after MOE reports)

MOE Site	location	latitude (° ' " N)	longitude (° ' " W)	n	mean total [^{226}Ra] 1984-87 ($mBq.l^{-1}$)
#001	Old Hwy 17 E of Hwys 108@17	46 12 40.9	82 30 43.92	20	75.6
#002	At lake Depot	46 20 7.52	82 32 22.78	20	21.6
#003	At Pecors Lake	46 22 26.74	82 26 16.91	11	85.3
#004	At Pecors Lake	46 23 36.85	82 29 54.14	13	165.0
#006	Crotch Lake	46 25 4.8	82 35 19.79	15	65.6
#007	Buckles Creek at Hwy 108	46 22 25.61	82 35 50.27	20	163.9
#009	Sheriff Creek at Hwy 108	46 24 9.12	82 39 49.8	20	72.5
#010	Rochester Creek Near Inlet to Quirke lake	46 29 57.97	82 31 24.36	7	54.3
#011	Serpent River near inlet to Quirke Lake	46 30 39.11	82 36 32.87	21	149.0
#012	Creek near road to Stanrock townsite	46 28 17.81	82 33 4.73	4	285.0
#014	Serpent R. at Panel Mine side rd	46 30 11.54	82 38 28.89	19	158.0
#017	Stollery L. at Denison dam	46 29 8.68	82 38 6.36	18	978.0
#019	Dunlop L. outlet	46 28 51.78	82 38 55.1	19	29.7
#020	Serpent R. Trib., Moose L. outlet	46 27 44.66	82 30 59.54	8	36.3
#023	Pronto Effluent at Hwy 17	46 12 6.4	82 41 52.59	19	87.0
#026	Serp. R. Trib. Panel Mine Tr plant out	46 30 27.99	82 32 21.51	23	314.0
#027	Elliot Lake Municipal Pumphouse	46 23 22.09	82 39 53.05	19	25.0
#030	Dunlop L. in Bay A	46 29 4.37	82 39 21.27	2	8.0
#031	Quirke L. SW of Stanrock Mine	46 28 6.32	82 34 14.73	3	77.0
#032	Quirke L. NE of CanMet Mine	46 29 13.97	82 31 44.24	2	80.0
#033	Quirke L. SE corner	46 28 20.44	82 31 49.77	2	75.0
#034	Quirke L. E of Denison Dam	46 29 10.87	82 35 31.64	2	75.0
#035	Whiskey L. S end Near Rum Point	46 24 27.28	82 20 56.9	2	60.0
#036	McCabe L., center of Lake	46 25 22.23	82 33 50.11	1	290.0
#037	Camp L., at S end	46 14 6.0	82 26 29.49	3	63.0
#038	Serpent Harbour, near Hospital Point	46 11 55.43	82 40 32.93	1	60.0
#039	McCarthy L., at W end	46 19 45.02	82 29 5.71	1	30.0
#040	McCarthy L., at S end	46 18 29.74	82 26 55.11	1	60.0
#041	Hough L., centre of lake	46 24 32.22	82 29 32.24	2	110.0
#044	Westner L. at ski club rd.	46 22 59.8	82 37 33.09	11	141.0
#045	Williams L. Creek, at Denison Mine rd.	46 29 44.31	82 38 7.43	12	163.0
#046	Pronto Ditch, below Pronto Treat. plant	46 12 15.39	82 42 41.86	4	75.0
#049	Serpent R., at Quirke L. outlet	46 29 14.25	82 29 20.01	20	132.0
#051	Quirke Mine Tailings	46 30 30.32	82 39 14.5	19	178.0
#054	May L., S end of lake	46 25 38.35	82 28 51.88	1	220.0
#055	May L., N end of lake	46 26 42.52	82 29 40.48	1	120.0
#056	Panel Creek at Quirke L.	46 30 11.16	82 33 7.95	4	135.0
#067	Esten L., central part of lake	46 21 4.28	82 41 50.51	1	7.0
#070	Orient L. outlet	46 27 30.74	82 31 10.88	14	70.0
#071	Panel Mine Tailings Effluent	46 31 8.36	82 32 30.86	13	230.0
#072	Gravel Pit outlet	46 31 7.57	82 41 5.92	16	13.0
#073	Evans L. outlet	46 29 37.89	82 39 55.13	19	18.0
#074	Esten L. outlet	46 20 39.4	82 36 55.01	19	50.0
Intermediate locations					
Stations					
051 & 011				40	162.7
009 & 044				31	96.8
007 & 074				39	108.6
014 & 011				40	153.4
067 & 074				20	48.3

APPENDIX V. Normality and data transformations

Underlying normality was inspected both graphically and numerically. Data on 57 bone ^{226}Ra estimates from beaver taken at Elliot Lake-low sites were plotted to reveal their frequency distribution:



Extreme skew (S_k = 3.146) in the raw data plot (left) suggested a lognormal distribution; this was confirmed by closer approximation to the normal curve when the data were log transformed and plotted (right). Transformation of the data brought mean and median values into proximity: before transformation their respective values were 48.38 and 38.00, after transforming they were 1.56 and 1.58. With this change, skewness (S_k) fell from 3.146 to 0.471. Transforming bone values from animals taken in 1987 and 1988 produced similar effects.

A Chi-square, goodness-of-fit test of a normal distribution for the same data data was carried out. Below are tables of working values for the nontransformed and log_{10} transformed data corresponding to this site:

Goodness-of-fit test of non-transformed data on beaver from Elliot Lake-low sites.

^{226}Ra Class From: (≥)	To: (<)	^{226}Ra X_i	Obs.Freq f_i	$f_i X_i$	$f_i X_i^2$	P(X_i)	Exp. Freq (F_i)	Exp Freq (F_i)	>1.0 $(f_i-F_i)^2/F_i$
< 9.4			0			0.18	10.49	10.49	10.49
9.40	47.25	28.33	37	1048.04	29686.36	0.03	1.58	1.58	791.53
47.25	85.10	66.18	15	992.66	65690.93	0.02	1.01	1.01	
85.10	122.95	104.03	2	208.06	21643.86	0.17	9.71	9.71	5.48
122.95	160.81	141.88	0	0.00	0.00	0.05	2.88	3.39	3.39
160.81	198.66	179.73	2	359.46	64606.11	0.01	0.47		
198.66	236.51	217.58	0	0.00	0.00	0.00	0.03		
236.51	274.36	255.43	0	0.00	0.00	0.00	0.00		
274.36	312.21	293.28	1	293.28	86015.80	0.00	0.00		
> 312.21			0	0.00	0.00	0.00	0.01		
			Σf_i = (=n)	$\Sigma f_i X_i$ =	$\Sigma f_i X_i^2$ =	ΣP (X_i) =		ΣF_i =	x^2 =
			57	2901.50	267643.05	0.46		26.19	810.88

H_o: This sample came from a normal population

H_a: This sample did not come from a normal population

X = 50.90

SS =119946.41

s^2 = 2141.90

s =.46.28

v = 8-3 = 5

x^2 (calculated) = 810.88

$x^2_{0.05,5}$ (table) = 11.07

Therefore reject H_o ($P < 0.05$)

Goodness-of-fit test: $\log_{10}$-transformed data of beaver from Elliot Lake-low sites.

log(Ra Class) From: (≥)	To: (<)	log(^{226}Ra) X_i	Obs. Freq f_i	$f_i X_i$	$f_i X_i^2$	P(X_i)	Exp. Freq F_i	Exp. Freq. F_i >1	>1.0 $(f_i-F_i)^2/F_i$
< 0.973			0			0.03	1.92	1.92	1.92
0.97	1.16	1.07	5	5.34	5.70	0.07	4.21	4.21	0.15
1.16	1.35	1.26	14	17.62	22.17	0.15	8.76	8.76	3.14
1.35	1.54	1.45	8	11.59	16.80	0.22	12.71	12.71	1.74
1.54	1.73	1.64	14	22.95	37.61	0.20	11.19	11.19	0.71
1.73	1.93	1.83	11	20.12	36.82	0.16	9.39	9.39	0.28
1.93	2.12	2.02	2	4.04	8.16	0.08	4.78	4.78	1.61
2.12	2.31	2.21	2	4.42	9.77	0.03	1.64	2.23	0.02
2.31	2.50	2.40	1	2.40	5.76	0.00	0.23		
> 2.495			0			0.01	0.36		
			Σf_i = (=n)	$\Sigma f_i X_i$ =	$\Sigma f_i X_i^2$ =	ΣP(X_i) =	ΣF_i =		x^2 =
			57	86.08	137.03	0.96	54.81		9.57

H_o: This sample came from a normal population

H_a: This sample did not come from a normal population

X = 1.51020175

SS = 7.02827393

s^2 = 0.12550489

s = 0.3542667

v = 8-3 = 5

x^2 (calculated) = 9.57

$x^2_{0.05,5}$ (table) = 11.07

Therefore, do not reject H_o ($P > 0.05$)